THOMAS A. EDISON IN HIS LABORATORY

Elec.—Vol. I. Frontispiece

ELECTRICITY IN EVERY-DAY LIFE

IN THREE VOLUMES

BY

EDWIN J. HOUSTON, PH.D.

Author of "A Dictionary of Electric Words, Terms and Phrases," "Electro-Technical Series," "Electric Transmission of Intelligence," "Electricity and Magnetism," "Electricity One Hundred Years Ago and To-day," "Recent Types of Dynamo-Electric Machines," "Electricity Made Easy," Etc.

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PREFACE

IN the preparation of "Electricity in Every-day Life," the Author has not hesitated freely to consult contemporaneous literature, including various books and periodicals, together with the records of scientific societies, which contain descriptions of the more important inventions in the electric arts and sciences.

He desires to acknowledge his indebtedness to Mr. Martin P. Rice of the General Electric Company and to Mr. C. J. Reed of Philadelphia and others for critical reading of some of the proof sheets. He also desires to acknowledge his indebtedness to the McGraw Publishing Company for several extracts from some of the books of Houston & Kennelly's Electro-Technical Series, Houston & Kennelly's "Recent Types of Dynamo-Electric Machinery," and Miller's "American Telephone Practice," as well as quotations from the "Electrical World and Engineer"; to Messrs. Appleton & Company for a brief quotation from Algave & Boulard's "Electric Arc Light"; to D. Van Nostrand Company for a quotation from Crocker's "Electric

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He also desires to acknowledge his indebtedness to William Maver, Jr., for several cuts from his book on "American Telegraphy."

The Author trusts that his book will prove of advantage to the general reading public.

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CONTENTS

FIRST PART

THE GENERATION OF ELECTRICITY AND MAGNETISM

I—ELECTRICITY OF HIGH ELECTRO-MOTIVE FORCE

CHAPTER VII

CHAPTER VIII

CHAPTER IX

CHAPTER X

CHAPTER XI

CHAPTER XII

CHAPTER XIII

II—MAGNETISM

CHAPTER XIV

CHAPTER XV

CHAPTER XVI

CHAPTER XXVIII

CHAPTER XXIX

V—ELECTRO-DYNAMIC INDUCTION, OR THE PRODUCTION OF ELECTRICITY FROM MAGNETISM

CHAPTER XXX

CHAPTER XXXI

FULL-PAGE ILLUSTRATIONS

VOLUME ONE

IN COLOR

IN BLACK AND WHITE

LIST OF ILLUSTRATIONS

ELECTRICITY IN EVERY-DAY LIFE

INTRODUCTORY

"There are more things in heaven and earth, Horatio,
Than are dreamt of in your philosophy."
—*Hamlet*, Act I, Scene V.

IT is no longer a matter of choice whether or not one shall become acquainted with the general facts and principles of electric science. Such an acquaintance has become a matter of necessity. So intimately does electricity enter into our every-day life that to know nothing of its peculiar properties or applications is, to say the least, to be severely handicapped in the struggle for existence. To-day one can not converse intelligently on almost any current topic without either, eventually, employing some electric term, or without referring to some electric fact or principle. Some of these references are to facts so well known that they have long ceased to appear to belong to electro-technology, and are regarded as matters of every-day life. Our current periodical literature fairly teems with electric words, terms or phrases. The daily newspapers employ electro-technical language as a matter of every-day necessity, quite as glibly as they do the rest of our mother tongue, and they do this, moreover, without the consciousness of employing anything more than the language of every-day life. In our households we talk of dynamos, motors, trolleys, electric lamps, telephones, and batteries, quite as freely as we do of bread, butter, butcher's meats, milk, ice, coal and carpets. We speak as

Necessity for general knowledge of electricity.

Electro-technical phraseology a part of our every-day language.

Common daily usage of electro-technical words, terms and phrases.

freely of electric pressure, of the candle power of our street or house lights, of the efficiency of our house 'phone, of the practicability of our electric gas lighting, of the use of our system of messenger, cab or police calls, of our burglar alarms, of the velocity of our electric fans, of the reliability of our house annunciators and electric door-bells, or other push-button apparatus, with no greater feeling of strangeness than we do of the action of the water or gas service in the house, the operation of the heater in the cellar, the use of the speaking tubes, or the operation of a carpet sweeper, lawn mower, coffee mill, water faucet, folding bedstead, sausage chopper or coffee pot. We speak of volts, ohms and ampères with almost the same intimacy as we do of coffee, sugar and tea. We are as ready to criticise the correctness of the registration of the electric meter as we are to accuse the butcher or the baker of gross overcharge, and make such statements with the same supreme consciousness of ability to confuse our opponent, whether he be the representative of the wicked monopolistic electric company, or merely the outside vender of our daily food supplies.

Thales, 600 B.C.

To form some idea of the wonderful growth in electric words, terms and phrases, compare the number employed to-day with that in the time of the Greek Thales, about 600 B.C., when one single word, "electron" or "amber," embraced the entire electric vocabulary, expressing as it did the only electric phenomenon then known to man. Or, take any English dictionary of say one hundred years ago, and see the comparatively limited number of words that can properly be called electrical, and then compare this with a modern dictionary, which will be found to contain more than twelve thousand separate (electric) words, terms and phrases, and this num-

The English dictionary of one hundred years ago and to-day.

ber growing daily to meet the needs of this constantly expanding science.

To form some idea of the extent of the growth in the applications of electricity in our every-day life, let us briefly follow, for a single day, some of the different workers in the various callings of life in any of our large cities. We will start with a lawyer, a profession not generally associated with any especial or unusual contact with electrical appliances. **Electricity as a part of our daily life.**

As our lawyer leaves his house, he boards a trolley car driven by electric motors, in dark weather electrically illumined, and in the winter, heated by electric heaters. The morning paper, almost certainly in these days printed by electrically driven presses, contains news collected from all parts of the world by telegraphic messages flashed over the land, cabled under the ocean, or wafted across space by systems of wireless telegraphy; or, it may be, collected by the spoken word through the intervention of the telephone. In this paper he reads both of the more startling electric achievements in different parts of the world, and of the every-day work of the electric arts and sciences. Doubtless, he consults the quotations of the stock market, collected by means of the electric stock-ticker. If the weather report interests him he can avail himself of weather forecasts, crystallized by expert meteorologists from the reports of the numerous skilled observers sent over the wonderful network of electric wires or conductors that our government employs in studying actual weather conditions in all parts of our country. In the police records, or in the proceedings of the courts, he reads of criminals at work being detected by the burglar alarm, or even by an alarm operated by the light of the dark lantern the burglar is so careful to hide from outside observation; or, he **Electricity in the daily newspapers**

may note the fleeing criminal as being arrested by the use of the telegraph or telephone, or cable, or, possibly, by means of his picture telegraphed to distant police stations. Or, perchance, he reads of a fire, started under circumstances that might have led to a great conflagration, stopped in its incipiency by some form of fire alarm, that might, as in the case of thermostatic alarm apparatus, have caused the increase of temperature automatically to send an alarm for the fire engines to come to extinguish the flames, or even automatically to turn on the water to do its own fire extinguishing, without the intervention of outside aid.

How electric service aids the police.

He might read much more of electric doings, but the rapid transit of the trolley system has brought him to his office in, say, a modern office building. Pushing an electric button, he calls an elevator, and rises rapidly to his floor, perchance in an electrically driven elevator. He enters his office and begins his day's work. If the day is hot he moves a switch and starts an electric fan. If the day is cloudy, and the office dark, he pushes a button, and instantly an electric illumination, as of day, lights up the office.

Usefulness of the speaking telephone in professional and business life.

He now opens his mail and begins reading his correspondence. Suddenly he hears a bell, and without leaving his desk, he listens at his extension 'phone and holds conversation concerning an important piece of work with a party in a distant part of the city; or, 'phoning a correspondent, he gives orders or directs the day's work, often far more efficiently than he could do personally, saving not only the time required for transit between his office and that of his correspondent, but, in addition, the time required while waiting in the outer office before he may have an interview; for, by the electric road that extends over the house-tops, on pole lines along the streets, through the underground conduits, under rivers,

through tunnels, etc., between his office and that of the correspondent, he travels as fast as Puck would in the days of Shakespeare, and almost immediately enters the private office of his correspondent and obtains an audience.

Need of electrical knowledge.

His mail finished, a client enters. The business may be a mere question of law not directly involving electricity. It may, however, be a question of a suit for damages, say, for injuries inflicted by a live electric wire, or for injuries sustained by the explosion of gas in an underground conduit, and then electric principles will be discussed and possibly the services of an expert engaged. Or, it may be a question as to the infringement of an electric apparatus or process, when an intimate knowledge both of the workings and operation of the apparatus is required, and familiarity with the prior state of the art is an absolute necessity. The ease with which the lawyer will discuss the case shows the familiarity he has already acquired, in common with the rest of the public, with the leading facts and principles of electric science. Possibly during the conference a technical word is used, the precise meaning of which is questioned; the lawyer quietly turns to his encyclopedic dictionary and determines for himself the best usages in the case.

The encyclopedic dictionary in everyday professional life.

The client dismissed, our lawyer leaves his office and goes to court and listens to or argues in different cases. In a murder case he may hear the verdict of the jury of "Murder in the first degree," and listen to the sentence pronounced by the judge, not to be hanged by the neck until dead, but "To be taken to the county prison, and there, on a set date, to be electrocuted, or killed by the passage of an electric discharge through the body, in the manner prescribed by the law."

Electrocution.

The court adjourned, lunch follows. In the club

house, or at the restaurant, the stock-ticker is personally consulted for the state of the money markets, and possibly an order to buy or sell is telegraphically or telephonically sent to his broker, or the printed page of the typewriting telegraph is consulted for the latest telegraphic or telephonic news from all parts of the country or world.

Telegraphic appointment for telephonic conversation.

During lunch a telegraph boy enters with a despatch from a distant city in the shape of a request from a client, fortunately not requiring a tiresome all-night or longer journey, but merely asking that he be called up at a certain hour on his 'phone, at such and such a number, say, in Boston. This agreed upon, at the appointed hour, in the twinkling of an eye, he passes over the long and tortuous metallic highway for electric passengers—*i.e.* the conducting wires—and enters his client's office in Boston, where he rapidly completes the business by giving his client the information desired, or agreeing on some course of proceedings to be followed until the next meeting.

The automobile and the electric launch.

Lunch over, a return to office duties, and, these completed, during summer months, a drive to the country club in an electrically driven automobile, or, possibly, a ride on the bay or river in an electric launch, with an inspection before leaving of the electric fountain with its wondrous color effects, obtained by light from powerful arc lamps on jets of water, whose play is obtained by means of electrically driven pumps.

Electricity at the theatre or the opera.

During winter, after a dinner at home, or at the club, a visit is made to the theatre or opera. Here, besides the electric illumination of the corridors and the main body of the house, are to be observed the splendid stage and scenic effects obtained by incandescent electric lights, or the gorgeous color effects obtained by the use of color screens in connection

with powerful arc projectors, or arc lamps furnished with focussing apparatus. On the stage itself, there may be displayed effects produced by brilliant electric jewels in the shape of miniature incandescent electric lamps. Here, too, he may observe the effects produced by variations in the amount, distribution or intensity of the electric illumination, though he can not see the means employed for the regulation of the electric lights necessary in order to obtain those effects. In the same manner he may see the results of the electric apparatus employed to produce sunrise effects, or of the reflectors employed to throw a powerful electric light on the actors so as to ensure a brilliant illumination of their faces or figures. He may also see the rainbow effects produced by the use of an electric arc and a glass prism.

Electric sunrise effects.

Having thus followed a lawyer through a day's work, let us do the same thing with a physician or surgeon, and see what practical applications of electricity or magnetism he might be obliged to use during a day's ordinary practice. Here the electric uses and applications are far more specialized than in the case of the lawyer; still they are by no means beyond the comprehension of the general public, who now regard them rather as matters of course than as causes for wonderment.

The physician's use of the faradic battery or induction coil.

During his office practice when occasions arise to give electric treatment, our physician or surgeon may have recourse to the faradic battery, by means of which electric currents, which rapidly change their directions, are obtained by the use of induction coils, provided with mechanism for rapidly breaking the circuit of a voltaic current passing through them; or, he may have recourse to magneto-electric faradic apparatus, in which currents that rapidly alternate, or change their directions, are obtained by the rotation, before the poles of a permanent or steel mag-

net, of a coil of insulated wire wrapped on a soft iron armature. Should he require the direct current, or a current which always flows in one and the same direction, he employs the current of a voltaic battery, where a number of wet or dry voltaic cells are suitably connected together. If a patient requires the use of the discharge from a frictional electric machine or its equivalent, our modern physician generally employs a variety of machines called static-induction machines.

Electric illumination of the interior cavities of the human body.

Should occasion arise to examine the nose, throat or ear of the patient, the doctor can call to his aid the direct illumination of these organs by means of powerful miniature electric lamps introduced directly into the neighborhood of the parts to be examined. He can even in this manner make an examination of the bladder by means of electric illumination obtained from a lamp introduced into this organ. In a similar manner he can make examination of other internal organs of the body, such as the stomach, etc. Or, instead of introducing the electric lamps directly into the parts to be examined, he may employ electric illumination indirectly by throwing, by the aid of suitable reflectors, the light of an electric lamp, which he supports on a band attached to his forehead, on to the part to be examined. In this way the eye, ear, throat, etc., are readily examined.

X-ray apparatus in surgical diagnosis.

A patient enters from a machine shop with a minute splinter of iron in the eyeball. If not readily removed by ordinary means, it may, under favorable circumstances, be directly removed by the use of a suitably shaped but powerful electro-magnet. If not in sight, the use of the X-ray apparatus discloses its location and enables the surgeon to decide whether an operation is advisable or possible, and thus premits him to properly diagnose the case, and make a

correct prognosis, or opinion as to the ultimate result of the injury.

In the hospital our surgeon may have a case of supposed fracture of some of the bones of the body. Instead of subjecting the patient to the old and now barbarous practice of moving the injured member until the broken surfaces of the bones grind or grate against one another, or "crepitate," the use of the X-rays will enable the surgeon to look directly through the flesh and tissues at the bones as readily as if they were bared of all their coverings and spread out directly before him.

X-ray apparatus vs. the probe.

A patient is brought into the accident ward with a gunshot wound. Instead of the old and painful probing for the ball, an examination by the X-rays at once locates its position with certainty. In the same way the position of foreign metallic bodies, such as needles, which, as is well known, slowly move from one part of the body to another, can be readily and accurately determined.

If it be desired to obtain permanent records of the position of any foreign body located by means of the X-rays, a photographic picture of the bodies and their surroundings can readily be obtained by means of X-ray photography.

All this the doctor or surgeon can do by electric means, and far more, as will be explained in greater detail elsewhere.

Electricity in the life of the artisan or laborer.

Going now into another calling, take an artisan, mechanic or laborer. No matter what his trade, it will be strange if in his daily work he does not come into frequent contact with electric devices, or find occasion to use all the electric knowledge he may possess.

If he is a bricklayer, and engaged in laying a pavement or street covering, he will, probably, be cautioned not to permit his laborers, in getting the

Underground conduits for electric conductors.

excavating done and preparing the surface, to injure the electric wires or conductors in the underlying conduits or electric tubes placed under the pavements or streets. He lays his bricks in the pavement, often quite up against the electric light poles or the trolley poles, with whose use he is so familiar. Perchance, he may be employed to brick up a man-hole or vault in a street where a system of underground conduits is laid. Then he can see the end of the terra-cotta tubes, or the rectangular conduits formed of creosoted boards, or the tubular conduits formed from creosoted logs. He can see the lead-covered cables that form the conductors of the electric light, power, or telephone circuits, which pass through the underlying conduits under the different streets. Or, he may see the iron-covered tubes that convey the Edison electric light wires or conductors.

Electric conductors in the modern skyscrapers.

Perhaps he may be employed in laying the bricks in the walls of one of our modern skyscrapers, or the hollow terra-cotta tiles for its partition walls. Here he can hardly avoid seeing the network or systems of conducting wires that are being installed in the more nearly completed portions of the building for electric light or power, or for telegraphic or telephonic service, messenger calls, fire or burglar-alarms, systems of thermostatic regulators, etc.

If a carpenter, plumber or gas or steam fitter, he would have in the same building even a better chance to observe the network of wires above alluded to.

Electricity in the machine shop.

If a mechanic in a large up-to-date machine shop, he would see nearly all the machine tools driven by separate electric motors. He would see heavy pieces of machinery, weighing probably tons, readily lifted and carried from one place to another by the use of electrically operated travelling cranes. Of course, such a shop is lighted by electric arc and incandescent lamps, and an electric locomotive is, probably, em-

"SEEING NEW YORK"

A large electric public conveyance, which makes regular trips around the city. "To see New York" is doubtless the cherished ambition of many of us. It is especially appropriate that electricity should be invoked for conveyance in seeing this very modern city

ployed to shift cars from one part of the works to another on the private tracks of the shop.

If sent to erect and install a system of boilers and steam engines in a large office building, he will have an opportunity to see the dynamos or electric generators, the switchboards with the various electric instruments employed to indicate the pressure, amount of flow of electric current, etc., while all around, he will see wires and electric apparatus, much of which will be unintelligible to him, so far as its minute details are concerned, but of the general use of which he is fairly well informed. Or, he may have an occasional opportunity to see the electric plant in his own shop, where he may be able more carefully to study it in detail.

Electric switchboard and generating plant of modern office building.

If he be a workman in a mill, say a cotton mill, in an up-to-date plant he will see numerous applications of electricity. The building is electrically lighted, the different machines, etc., are electrically driven, and, possibly, even the power required to light and drive the mill is generated at a distant waterfall, and electrically transmitted to the mill. In this case the alternating current apparatus is probably employed, and a great variety of apparatus will necessarily be employed, such as step-up and step-down transformers, induction motors, rotary transformers, etc.

Electricity in cotton mills.

If he be a miner, say, in a mountainous district, several years ago he would have been in an almost hopeless location to look for electric appliances; but not now. In an up-to-date mining installation he can not fail to see much that is electrical. In many localities the situation of the mine is such that electricity is practically the only power that could be employed, since in many such localities wood, water and coal are not available. Consequently, in such a mine might be found electrically lighted tunnels

Electricity in mining.

and mine buildings, electrically driven hoists, pumps, drills, blowers and mills, and electrically driven air compressors, to furnish air for operating drills and forges. In some of the larger mines in the Western United States, the extent of the electric plants required to carry on the different operations of mining almost passes belief.

Electricity on the modern warship.

But let us again go into an entirely different line of work and take, say, one of the United States marines on board a modern warship. Such a worker during a day's duties might have an opportunity, should discipline so permit, for noting the wonderful extent of the application of the electrical sciences in the floating sea terror, and he may lie in his bunk during his hours of rest and be thankful for the fact that, so far as safety from ordinary leakage is concerned, the electric wires or conductors which in modern vessels have replaced the old steam pipes, require less cutting and have weakened the watertight compartments to a much smaller extent. During action, too, he is less liable to being boiled to death by escaping steam, so dreaded during a sea fight on the cutting of steam pipes by shot.

A few of the many electric appliances on the man-of-war.

Let us now but briefly note what the marine might see in greater detail. We say "might see" advisedly, since to many parts of the warship he is necessarily a stranger. In the first place, he will find an electric generating plant that excites his surprise from its size and diversity. Here he might find dynamos for feeding incandescent lamps for general illumination, and arc lamps for the powerful searchlights. Generators for furnishing currents to the countless electric motors required for turning or elevating the turrets, operating the rammers, or the turret ammunition-hoists, for driving the blowers required in the system of forced draughts employed on all modern warships, for working the pumps, boat

cranes, capstans, ash-hoists, steering apparatus, the numerous ammunition-hoists for the batteries, warship tools and laundry apparatus, to say nothing about that required for the portable fans, helm indicators, and other electric signalling devices. In addition to these, there are the numerous telephones, call bells, buzzers, together with a fire-alarm system and the necessary annunciators; the electric thermostats, general signal alarms, electric engine-telegraphs, to indicate the need of an increase or decrease in the number of revolutions per second, electric lamp indicators for various purposes, helm-angle indicators, revolution and direction-indicators, battle and range-order indicators, besides numerous other important devices, dependent for their operation on electricity.

Various alarm apparatus and indicators.

Going now into a still different sphere of life, let us take the boy or help on one of our Western farms. Here the opportunities for observation are necessarily limited. Still, in general, the boy knows the telephone by actual use, and, in many localities, he uses the trolley car, and can, therefore, see the operation of the electric motor, the incandescent electric lamps, and can study out the action of the system of feeder wires, no longer buried in underground conduits, as in our large cities. Besides all this, he lives in a district where the lightning rod man is around, and he can therefore pick up more or less reliable information how the particular rod each vender recommends acts in diverting the dangerous bolts that may strike the neighborhood of the house or barn he is professedly so anxious to protect. Besides all this, he lives, perchance, in the neighborhood of some large town or city, a visit to which greatly increases the limits of his possible studies.

But even our farm boy or hand, shut off from the opportunities above referred to, may occasionally

Electricity and the boy on the farm.

see the palace cars on the railroad, with their electric incandescent lights, and where this is impossible, he can get the newspapers, or the magazines, that teach him of the electric wonders in the great world in the "east" or "furthest continental west," and must content himself to be satisfied for the actual sight of electric phenomenon, with the occasional northern lights, or aurora borealis, or the more frequent lightning bolt, so especially dangerous when the hay harvest has just been placed in the barn.

Electricity in a modern daily newspaper.

In order to show the extent to which electrical doings and interests get into our daily newspapers, we will take the morning's issue of a representative paper, say the "Sun" of New York City, and call attention briefly to some of the matter contained therein.

Among the advertisements we find one from the United States Government, asking for proposals for an electric power plant in one of its public buildings; also a notice of a $750,000 installation of a mill, cyanide plant, water works, and electric plant, for the famous Tonopah Gold Mines in Nevada.

Commercial Cable Company.

As one of the many straws that show the direction of the financial currents as to large investments in electrical interests is the declaration of a regular quarterly dividend by the Commercial Cable Company. This is the company that controls the Mackay-Bennett cables. It is a corporation, organized under the laws of the State of New York, and owns and operates the three trans-Atlantic cable lines, and their connecting cables, between Ireland and France, and Nova Scotia and New York, with a total length of cables of 9,110 miles. In January of 1897, this company purchased the land lines of the Postal Telegraph Cable Company, a concern that then had under its organization some 117,000 miles of land service. The stock issue of this company is $10,-

000,000. It has a funded debt of some $18,000,000 under an issue of bonds amounting to $20,000,000, authorized for the purpose of merger with the Postal Telegraph Cable Company. Of this issue, $15,000,000 in bonds were in exchange for the Postal Company's shares, and $5,000,000 were reserved for the extension of the telegraph system. We give the above figures merely to show the extent of the financial interest of companies that are purely electrical.

Postal Telegraph Cable Company.

There is to be found the announcement of a dividend by the Western Union Telegraph Company. This is a still greater giant among electric corporations. Its capital stock in 1900 was $97,370,000. This company in 1898, had in operation 189,856 miles of poles, on which were strung 904,633 miles of conducting wires. It did a business for that year of 61,398,157 telegraphic messages, for which it received $23,954,312. Since these messages cost the company $18,085,579, the profits were $5,868,732.

The extent to which the electric light and the telephone are introduced into modern dwellings and hotels will be seen from the many advertisements of houses for sale or rent, specifying that electric lighting and telephones are installed on the premises.

In some brief notes on naval progress, reference is made to the searchlights on several United States cruisers. The same paper contains an article on a safety dress for electricians, invented by Siemens & Halske. This dress is designed to protect the wearer from the deadly effects of high-voltage discharges.

Electric searchlight.

An article on the X-ray apparatus and its installation in New Orleans calls attention to the effect on the proper working of the electric apparatus produced by excessive moisture.

As showing the extent to which electric apparatus has spread to practically the remotest ends of the

earth, we note a description of the unique city of Dalny, near the Pacific Ocean, in Russian Siberia.

Dalny, Russian Siberia.

"The unique thing about this new city is that it begins its municipal life with all modern improvements. There are piers of stone and cement; a large breakwater, with no ships to seek refuge behind it. The streets are graded and paved, although there is no traffic for them as yet. The different quarters of the town have been laid out, space provided for parks, schools, churches, etc. Gardeners are already beautifying the parks. Electric lights and electric railways are already in operation. As yet not a foot of land has been sold, although over $6,000,000 have been expended for improvements and public buildings. The population now exceeds 50,000, 23,000 of whom are employed in building the railroad, which is to be owned by the Russian Government."

No danger of Niagara running dry yet.

The demands made by the Twentieth Century for cheap electric power are now so great that a correspondent inquires whether any danger exists from so much of the water of Niagara Falls being diverted for the driving of water wheels connected to electric generators as to cause the falls to run dry.

The above are but some, but by no means all, of the references in a single issue of the daily newspaper above referred to. We might give more from this issue, but the above will suffice.

It appears, then, that in every walk of life a knowledge of electricity that is by no means limited to mere superficiality is necessary in order to talk or to read intelligently, even for those who do not intend to become directly interested in its practical applications. A knowledge of the more important electric phenomena, of the laws which govern them, and of the manner of operation of their more important applications, can be acquired by the general

public without any previous acquaintance with the higher mathematics, or any college or high school training. It is the object of this book to impart to the general public that knowledge in electricity which it should have, and to make this knowledge as full and complete as may be possible.

Object of "Electricity in Every-Day Life."

FIRST PART

THE GENERATION OF ELECTRICITY AND MAGNETISM

I

ELECTRICITY OF HIGH ELECTRO-MOTIVE FORCE

CHAPTER I

THALES AND THE RUBBED AMBER—SOME EARLY HISTORY OF ELECTRICITY

"We will concern ourselves only with the greatest, the epoch-making men, to whose life and work we and all who come after them owe so much. Such a man was Thales."—*Pioneers of Science:* OLIVER LODGE.

THE wonderful extent to which electricity enters into our every-day life, as briefly set forth in the introductory matter to this book, would naturally lead one to believe that the existence of the electric force must have been known in very ancient times. In point of fact, however, electricity is essentially a science of a comparatively recent date. The mighty force of electricity is so constantly manifesting itself in natural phenomena, and, moreover, is so readily produced, that it seems incredible that the ancients should have failed to acquaint themselves, at an early age, with at least its fundamental laws. It is true that some 600 years before the Christian Era it was known that a bit of amber, when rubbed briskly against the clothing, acquired the curious power of attracting or drawing to it such light bodies as bits of straw or feathers. There were acute observers, in those early days, with more or less trained eyes, but here, they were eyes that saw not. They attempted no reasonable explanation of the amber phenomenon, and thought so little of its importance that it was soon completely forgotten.

Electricity a comparatively recent science.

Thales, 600 B.C.

The pioneer discoverer of the electric power of rubbed amber was a Greek named Thales, born at Miletus, 641 B.C. Thales was a learned man. He may properly be called both a mathematician and physicist, since he made original investigations and discoveries in geometry, and was sufficiently far advanced in astronomy to be able correctly to predict the day and hour of a total eclipse of the sun. He spent some time in Egypt, from which country it is possible that he may have brought his knowledge of the curious property of rubbed amber, since we have reasons for believing that both the Egyptians and the Chaldeans, at this time, had acquired a fairly considerable knowledge of the phenomena of nature. A portrait of Thales is shown in Fig. 1.

Knowledge of the Egyptians and Chaldeans.

How little did the favored few to whom Thales showed this curious phenomenon understand its mighty significance. How little did they appreciate that it was a slumbering giant who was about to be aroused, and not an insignificant pygmy. Indeed, Thales himself does not seem to have understood, even to a limited degree, the vast importance of the physical fact he was the first to observe. Consequently, observation failed to lead to any practical results. Very little was thought of it by his contemporaries. Indeed, it was so imperfectly recorded, that some pessimistic critics of to-day are not unwilling to cast doubts as to whether Thales ever, in point of fact, made such a discovery.

Thales apparently ignorant of value of his observation.

Scheherazade, in the Arabian Nights, tells the Sultan a charming story of a certain Aladdin, only son of a poor widow in one of the provinces of China, who came into the possession of a priceless talisman in the shape of a magic lamp. If the fortunate owner of this talisman but rubbed the lamp, a Genie

The genii of electricity.

FIG. 1.—Thales, one of the seven wise men of Greece: reputed discoverer of first recorded electric phenomenon. Born 641 B.C., died 563 B.C. Taken from "Histoire des Philosophes Anciens," Paris, 1772.

instantly appeared and asked: "What wouldst thou have? I am ready to obey thee as the slave of the lamp, I and the other slaves of the lamp"; and, no matter what the demand, the story goes on to relate, it was instantly obeyed. Nothing was beyond its marvellous power. If Aladdin so commanded, he was instantly transported beyond the summits of the highest mountains in China. If he so desired, he was able to hear the faintest whispers, even though they were uttered hundreds of miles away. At his command, the choicest riches of the physical world were laid at his feet, night was turned into day, heavy loads were transported through great distances, and both time and space annihilated. As we read the story we are unable to suppress the desire to possess so valuable a talisman. With such aid at one's command what might not be accomplished? Happy age that possesses the help of such giant genii as those of Aladdin's lamp! What gigantic strides in the arts and sciences, in commerce, and in short in everything that tends to make man's life both profitable and happy would necessarily be made!

Aladdin's wonderful lamp.

But what had Thales done? He had electrified the amber by rubbing it. He had discovered the means whereby man could, at will, cause a hitherto undetected and powerful force to appear; a force which, as we now well know, is capable of doing mighty things. He had opened a door through which he might have seen some of the wonders and glories of a new realm of nature, but he saw them not.

Amber electrified by rubbing.

That little piece of amber rubbed by Thales, some 2,500 years ago, appeared then to be very insignificant. Had the world but known, it was fraught

with vast possibilities; for, in point of fact, Thales had unconsciously rediscovered Aladdin's Wonderful Lamp. As he rubbed, the Genie of electricity appeared, and demanded, "What wouldst thou have? I am ready to obey thee as the slave of the lamp, I and the other slaves of the lamp." But the question remained unanswered. Neither Thales nor the witnesses of his experiment made any request nor asked its genii to aid them. They had ears, but they heard not, and so the genie disappeared, with all that he was both willing and able to do left undone.

Powerful genii of electricity.

In a later, happier age, however, the genie of electricity is not invoked in vain. "What would I have?" says the modern owner of the lamp. "I command thee as the slave of electricity that thou, or some other of the slaves of electricity, transport me in the twinkling of an eye from New York to Chicago"; and, immediately, through the agency of the telephone, the command is obeyed, and the task accomplished. At the same command, the genii of electricity are ready to turn night into day, haul heavy loaded cars through streets, over mountains and plains, carry our thoughts from continent to continent across the ocean's bed, or waft them across wireless space from shore to shore. They are ready with their giant, though unseen, hands to drive the machinery of our great mills and manufactories, even though compelled to reach over transmission lines hundreds of miles in length. They are ready to heat our houses, cook our meals, cure our diseased bodies, and to do much else at the bidding of their masters. Is it any wonder that the world has made such giant strides in the useful arts and sciences, when such powerful genii are ready to obey its will without hesitation or questioning?

Work of the genii of electricity.

Classification of lightning strokes by the Etruscans.

The phenomena of lightning and thunder were necessarily well known both to Thales and contemporary philosophers. The Etruscans, as early as 600 years B.C., had carefully observed such phenomena, and had divided lightning strokes into those which come from the earth and those which come from the sky. They noted the fact that the former rose perpendicularly, and that the latter struck obliquely. They even claimed to be able to draw lightning down from the sky. Nevertheless, they apparently remained in profound ignorance of any of the physical properties of lightning, and naturally failed to connect lightning with the bit of rubbed amber. The Romans recognized two varieties of lightning, those of the day, which they attributed to Jupiter, and those of the night, which they attributed to Symmanus. It is stated that during the siege of Rome by Alaric some Etruscans informed the prefect of the city that they had seen cities protected by lightnings and whirlwinds of fire, drawn down from the sky, which destroyed their enemies; and that they could do the same for Rome, but, after repeated trials, they utterly failed to fulfil their promises.

Classification of lightning strokes by the Romans.

Etruscans and the Roman prefect.

Bible references to lightning and thunder.

Even long before the time of the Etruscans we have records of both lightning and thunder. The Bible makes such reference as early as the days of Moses, 1491 B.C., as follows: "And it came to pass on the third day, in the morning, there were thunders and lightnings, and a thick cloud upon the mount, and the voice of the trumpet exceeding loud, so that all the people that were in the camp trembled" (Exodus xix. 16). Even at a much earlier date, 1540 B.C., we find the following almost prophetic saying of Job: "Canst thou send lightnings, that they may go and say unto thee 'Here we are?' " (Job xxxviii.

Moses, 1491 B.C.

Job, 1540 B.C.

35); or, as is still more significant in the original Hebrew, "Behold us." Later, in the days of Jeremiah, 595 B.C., we have, "When he uttereth his voice, there is a multitude of waters in the heavens; and he causeth the vapors to ascend from the ends of the earth; he maketh lightnings with rain, and bringeth forth the wind out of his treasures" (Jeremiah li. 16). There are many other references in the Bible, but those already given will suffice.

Jeremiah, 595 B.C.

It was, however, one thing to have known the phenomena of lightning and thunder, and another to have demonstrated their cause to be the passage of electric discharges through the atmosphere, as was afterward done by Franklin, at a much later date (A.D. 1752). Thales' observation, therefore, about 600 B.C., remains the world's first recorded electric phenomenon. It was, perhaps, as great a discovery as has ever been made in the physical world, at least, so far as its significance is concerned. But, for some reason or other, it utterly failed to bear fruit, and was so completely forgotten that, when Theophrastus, about 321 B.C., discovered that a mineral called lyncurium, which is believed to be either tourmaline or the hyacinth, when rubbed acquires the power of attracting light bodies, the announcement seemed like that of an entirely new discovery.

The world's first recorded electric phenomenon.

Theophrastus, 321 B.C.

Theophrastus' discovery shared the same fate as that of Thales, and failed to produce practical results. It was not until a much later date, A.D. 1600, that Dr. Gilbert, physician to Queen Elizabeth, repeated these early experiments and added a number of substances besides amber and lyncurium that were capable of producing similar results. From this time the science of electricity may be said to have had its true birth.

Gilbert, A.D. 1600

Among the other substances found by Gilbert to possess properties similar to amber and lyncurium when rubbed may be mentioned the diamond, sapphire, rock-crystal, sulphur, resin and sealing-wax. Gilbert called such substances ideoelectrics, or simply electrics, from the Greek word *elektron*, or amber, and in this way the name electricity came to be applied to the cause or agency which produced the phenomena. After Gilbert's time numerous investigators appeared, but it will be impracticable to take them up in detail, though some references will be made to many of them in describing electric phenomena. For the present it will suffice to quote the following from a book by Cavallo, published in London in 1795:

Ideoelectrics or electrics, and anelectrics or non-electrics.

Tiberius Cavallo—quotation from.

"After Gilbert, the science advancing, although by small degrees, passed, as it were, from infancy to puerility; many an excellent philosopher undertaking to examine nature in this walk: such was Sir Francis Bacon, Mr. Boyle, Otto Guericke, Sir Isaac Newton, and most of all, Mr. Hawkesbee, a person to whom we are much indebted for many important discoveries, and a real advancement of Electricity. Mr. Hawkesbee was the first who observed the great electric power of glass; a substance that, since his time, has been generally used by all electricians, in preference to any other electric. He first remarked various appearances of the electric light, and the noise accompanied with it, together with a variety of phenomena relating to electric attraction and repulsion.

Bacon, Boyle, Guericke, Newton and Hawkesbee

"After Mr. Hawkesbee, the science of Electricity, however hitherto advanced, remained for about twenty years in a state of quiescence, the attention of philosophers being at that time engaged in other philosophical subjects, which, on account of the new discoveries of the incomparable Sir Isaac Newton, were then greatly in repute. Mr. Gray was the first,

Cavallo's idea of the beginning of the flourishing era of electricity.

after this period of oblivion, to bring the science again to light. He, by his great discoveries, reintroduced it to the acquaintance of philosophers, and from him the true flourishing era of Electricity may be said to take its date."

A method of ascertaining whether a rubbed body has acquired electric excitement is to employ a simple piece of apparatus called the electric pendulum. This consists of a small ball of elder pith, suspended by a thread, as shown in Fig. 2. When Electric pendulum.

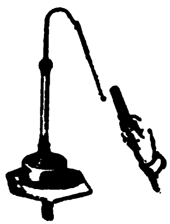


FIG. 2.—The Electric Pendulum. Note the attraction of the pith ball, thus indicating the electrification of the appended rod. Note also the glass supports provided to prevent the escape of the electric charge.

we approach a rubbed body, say a rod of sealing-wax, or a glass tube, to the pith ball, if attraction follows, as is indicated in the figure by the pith ball being deflected from its former position vertically below the point of attachment of the supporting thread, the rod of sealing-wax, or the glass rod, is correctly judged to have been electrified by friction.

There were many substances, such as the metals, in which Gilbert was unable to produce any electric effects by rubbing or friction, while holding them in his hand. These he called anelectrics, or non-electrics. It is now well known that, in such cases, electricity was produced by the friction, but was imme- All substances electrics.

diately conducted away and dissipated; that such substances, if mounted on glass handles, are readily excited by friction. In other words, electricity can be produced in all substances by friction.

A classification of electricity.

Electricity produced in this manner by friction was formerly called frictional electricity in order to distinguish it from thermo-electricity, or electricity produced by heat; voltaic-electricity, or electricity produced by the voltaic pile; magneto-electricity, or electricity produced by magnetism; and vital electricity, or electricity produced in the bodies of living plants or animals. These terms, though convenient as indicating the source of the electricity, are generally falling into disuse, since, as is now well known, no matter what its origin, all electricity is one and the same, differing only in certain well known ways, which will afterward be explained.

Excited bodies.

Electrification.

Bodies in which electricity has been produced in any way, as, for example, by friction, are said to be excited or electrified, and the process, or means by which this excitement has been produced, is called electrification.

CHAPTER II

ATTRACTION AND REPULSION—CONDUCTORS AND NON-CONDUCTORS—SOME OLD THEORIES OF ELECTRICITY

"No one supplied Gray with means, pecuniary or otherwise, for the prosecution of his work, but that did not trouble him. There were his fishing rods, and his canes, the kitchen poker, and cabbages and pieces of brick; hemp twine was cheap, and by getting along with them, he could economize sufficiently to acquire the more expensive part of his apparatus, a little silk and a few glass tubes. If a suspended boy was wanted, no doubt there were plenty of Grey Friars' lads willing enough to undergo the astonishing experiences which the old brother contrived for them."—*The Intellectual Rise of Electricity:* PARK BENJAMIN.

A DRY, hard-rubber comb, which has been slightly warmed to drive off the film of moisture, that is apt to adhere to its surface, if briskly rubbed with a warmed, dry, silk handkerchief, will become electrified, and, like the rubbed amber, will attract light bodies. Moreover, if the air be dry, when brought near the face the comb will cause a creeping sensation, as though cobwebs were touching it. A knuckle of the hand, when approached to the comb, will occasion crackling sounds to be heard, and, in the dark, faint bluish sparks will be seen to pass between the comb and the hand. All these effects are due to the discharge of the electricity produced on the comb by friction.

Some effects produced by electrified bodies.

A rod of dry glass, or a stick of sealing-wax, rubbed briskly with a silk handkerchief, is readily

Attraction of electrified bodies by an electrified rod.

electrified, and, if brought near small shreds of dry paper, or particles of dried chaff, preferably laid on

FIG. 3.—Effects of Electrified Rod. The approach of the rod causes an active motion in the small particles of paper, which move rapidly between the rod and a sheet of paper on which they rest.

a sheet of dry paper, will cause their attraction as shown in Fig. 3.

But attraction is not the only effect. It will be noticed, in all cases of electric attraction, that the attracted bodies, as soon as they touch the electri-

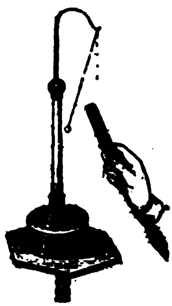


FIG. 4.—Electric Pendulum, showing electric repulsion. Compare this with Fig. 2, and note that in electric attraction the pith ball is drawn or pulled up from its vertical position when at rest, while in electric repulsion it is pushed up from such vertical position.

fied body, are driven away or repelled from it. This is especially noticeable in the case of the electric pendulum shown in Fig. 2. As soon as the pith

ball touches the electrified body it is repelled, assuming the position shown in Fig. 4, being now driven away from the approached electrified body.

All substances, whether solids, liquids, or gases, can be electrified by friction, although it is much easier to produce electricity in some substances than in others. The metals, for example, which Gilbert thought incapable of electrification, readily manifest electric effects if rubbed when mounted on glass handles. When a glass rod or a stick of sealing-wax is rubbed, only the part rubbed is electrified; the parts not rubbed remain unelectrified, and are unable to produce either attraction or repulsion; moreover, if touched, such bodies only lose a portion of their charge. But when a metallic body is electrified on any part of its surface, the electricity instantly spreads over all remaining parts of its surface, and, if touched by a metallic body connected to the ground, the charged body instantly loses all traces of electrification. In other words, metallic bodies conduct electricity, while glass and sealing-wax do not conduct it. All substances may be divided into conductors of electricity and non-conductors of electricity. When a conductor of electricity is supported on a non-conductor it is said to be insulated. Non-conductors are, therefore, also called insulators.

Conductors capable of electrification by friction.

Electric conductors and non-conductors.

Insulators.

The discovery of the conducting and non-conducting power of different substances was made in 1729, by an Englishman named Stephen Gray, a fellow of the Royal Society, and connected with the famous old Grey Friars' School. Gray found that an excited glass tube readily transmitted its charge to a metallic ball suspended from one end of the tube by threads of linen, hemp, or by metallic wires, but failed to do

Discovery of electric conducting and non-conducting powers.

so when suspended by a thread of silk. In order to readily determine whether the ball was charged he held it over light objects and noted whether they were attracted or not. Linen and metal, therefore, conduct electricity, and silk does not.

Experiments on an electrified boy.

By suitably supporting a hempen thread by means of silk thread, Gray was able to transmit electricity through it for a distance of 886 feet. Gray proved that the human body is a conductor of electricity by suspending a boy by means of silken cords. Under these circumstances, when any part of the boy's body was electrified, sparks could be drawn and electrical effects obtained from any other part of the body. This is shown in Fig. 5, by the quaint picture of an early experimenter and his audience taken from an old French book.

Powers of electric conduction and non-conduction, relative.

Substances differ greatly in their ability to conduct electricity. All substances, even those called non-conductors, have some little conducting power for electricity, and all conductors offer some resistance to the passage of electricity, or act to some extent as insulators. In the following table, the names of some common substances are arranged in the order of their ability to conduct electricity. The good conductors, therefore, come first in the list, and the poorer conductors last. But such a list may be read from the bottom upward as a list of non-conductors. In either case, the partial conductors, or the partial insulators, will occupy an intermediate position.

List of conductors.

Metals	Conductors
Well burned charcoal	
Graphite	
Acids	
Water	
The human body	

By Courtesy of the Scientinc American

ELECTRICITY IN AGRICULTURE.—A THRESHING MACHINE

Agricultural implements of all sorts are now being made to run electrical'y. "The good old times" are now well passed; a farmer may ride over his land sowing, cultivating, and reaping, in electric vehicles, in place of the old back-breaking way

Fig. 5.—Demonstration of the conducting power of the human body. Note the electric spark being drawn from the boy's nose, also the attraction of the pith balls to his left hand held over the small table. Note also the glass rod held in the hand of the lecturer, and used to electrify the boy.

List of partial conductors.

Linen Cotton Alcohol and ether Dry wood Paper	Partial conductors

List of non-conductors or insulators.

Oils Porcelain Silk Resin Gutta-percha Shellac Ebonite Paraffine Glass Air	Non-conductors or Insulators

Electric resistance.

The differences in the conducting power of different substances is due to what is called their electric resistance. In good conductors this resistance is small: in non-conductors it is great. The electric resistance of all bodies increases with their length,

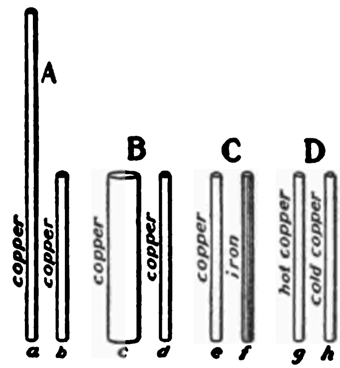


FIG. 6.—Electric Resistance. Note here that for an iron rod to have the same resistance as a copper rod of the same length, it must have an area of cross-section six and one-half times greater.

Influence of dimensions, temperature, and nature of conductors on their electric resistance.

and decreases with their area of cross-section. Thus at A, Fig. 6, the copper rod *a*, of the same thickness and area of cross-section as the copper rod *b*, but twice its length, has twice the resistance. If these rods be cut in half, the resistance of each half

will thereby be made half what it originally was. At B, if the copper rod *c* has the same length as the copper rod *d*, but four times the area or cross-section, it will have a resistance but one-fourth that of *d*. At C, are two rods of the same length and thickness, but one, *e*, is of copper, while the other, *f*, is of iron. Here the resistance of the iron rod, at ordinary temperature, is some six and a half times greater than that of the copper rod. In other words, the resistance of a rod of iron of a given length and area of cross-section is six and a half times greater than that of a rod of copper of the same dimensions. This is called the specific resistance, or resistivity. At D, the rods *g* and *h* are both of copper, and have the same length and area of cross-section, but *g*, which is hot, has a resistance somewhat greater than *h*, which is cold.

Specific resistance or resistivity.

The practical unit of electric resistance is called the ohm, from Dr. Ohm, a famous German electrician. The ohm is the resistance, at the temperature of melting ice, of a column of pure mercury, whose length is 106.3 centimeters, and whose area of cross-section is one square millimeter. Roughly, the ohm is the resistance of two miles of ordinary copper trolley wire; or, it is the resistance, at the temperature of forty-five degrees Fahrenheit, of one foot of a very thin pure copper wire called number 40, of the American wire gauge.

Dr. Ohm.

The practical unit of electric resistance, or the ohm.

An electrified body is said to possess an electric charge. When an electrified body is brought into contact with a conductor it loses its charge and is said to be discharged. An electric discharge produces an electric current—that is, a flow or passage of electricity through the conducting path along which it is discharged. The electricity in charged

Electric charge and discharge.

Electric currents.

Static electricity and current electricity.

bodies is at rest. Such electricity is, therefore, sometimes called static electricity, in order to distinguish it from electricity in motion, which is sometimes called current electricity. The science which treats of electric charges is called electro-statics.

Electro-statics.

If the pith ball in the electric pendulum of Fig. 4, while being repelled by a silk-rubbed glass rod, is approached by a flannel-rubbed rod of sealing-wax, it is no longer repelled, but attracted. Or, if a silk-rubbed glass rod, suspended by a silk thread, so as to be free to move, is approached by another silk-rubbed glass rod, it will be repelled; but, if approached by a flannel or fur-rubbed stick of sealing-wax, it will be attracted. Trials made in this way will show that all bodies electrified by friction act either like the silk-rubbed glass, or the flannel-rubbed sealing-wax. It is evident, therefore, that there are but two kinds of electricity. Early experimenters called these vitreous electricity, or the electricity produced by rubbing glass, and resinous electricity, or the electricity produced by rubbing resinous substances. It is now known that the kind of electricity produced by rubbing either glass or resin depends also on the substance with which the glass or resin is rubbed. For example, glass rubbed by cat's fur yields resinous electricity, and resin rubbed by a sheet of leather, over the surface of which is spread a soft amalgam of tin and mercury, yields vitreous electricity. The terms vitreous and resinous electricity have, therefore, been replaced, at the suggestion of Franklin, for the terms positive electricity, or that produced by silk-rubbed glass, and negative electricity, or that produced by wool-rubbed sealing-wax.

Vitreous and resinous electricity.

Positive and negative electricities.

In the accompanying list the order of arrangement of a number of common substances is such that

if any two of these substances be rubbed together, the one coming earlier in the list will be positively electrified, and the one coming later in the list negatively electrified:

List of positive and negative substances.

Cat's fur, wool, glass, cotton, silk, the hand, wood, sealing-wax, shellac, resin, metals, sulphur, india-rubber, gutta-percha, and celluloid.

Thus, glass is negatively electrified by fur and positively electrified by cotton or silk. All resinous substances are negatively electrified by fur or silk, but positively electrified by celluloid.

Forbes.

Effect of nature of rubbed surfaces and temperature on character of the electrification produced.

The kind of electric charges produced by friction, whether positive or negative, depends on the character or the condition of the surfaces rubbed together as well as on the nature of the substances themselves. Thus, as Forbes has shown, rough glass might be placed in the above list of substances after shellac. Even the color of the surface has an influence on the kind of electrification produced; thus, black silk rubbed with white silk is negative. So also the temperature of the surface influences the character of the charge. Hot cork is negatively electrified by friction against cold cork.

The mere contact of dissimilar substances is known to produce electric charges and the production of electricity by friction has been correctly ascribed as an effect due to contact between the rubber and the thing rubbed.

Single and double-fluid theories of electricity.

Whenever electricity is produced by friction both the rubber and the thing rubbed are electrified by equal but opposite charges. In silk-rubbed glass, the positive charge on the glass is exactly equal in amount to the negative charge on the silk. Various theories have been proposed to account for electric

phenomena. Two of the earliest of these are the double-fluid theory and the single-fluid theory of electricity.

DuFay and Symmer's double-fluid theory.

The double-fluid theory, proposed both by a Frenchman named DuFay and an Englishman named Symmer, assumed that all substances contain an indefinite quantity of an imponderable, neutral electric fluid, formed by the union of two separate electric fluids, the positive and the negative; that in unelectrified matter these two fluids combine with and neutralize each other; that electrification consists in their separation. Consequently, when a body is electrified by friction, the work done by the rubbing results in the separation of the two fluids, the rubber retaining one electric fluid, and the thing rubbed the other electric fluid.

Franklin's single-fluid theory.

The single-fluid theory of electricity, proposed by Franklin, assumes the existence of a single, extremely tenuous and weightless or imponderable fluid, existing in all matter. This electric fluid is strongly attracted by all matter, but its own particles are strongly mutually repellent. All bodies are capable of containing a certain quantity of the electric fluid without manifesting any electric excitement, but when a body contains either a surplus or a deficit of this fluid it manifests electric excitement. The act of friction gives to one of the bodies an excess of the fluid, thereby imparting to it positive excitement, and leaves the other body with a deficit of the fluid, thereby rendering it negatively excited. For this reason positive electricity is frequently indicated by a +, or plus sign, and negative by a —, or minus sign. These symbols are convenient, and are very generally employed, irrespective of any theory.

Plus and minus charges.

Neither the double nor the single-fluid theory is credited at the present time. Merely as a matter of convenience, the single-fluid theory has been accepted by some with the modification, that is believed advisable from some phenomena presented by the motion of the residual gas in Crookes' tubes during electric discharges, that the negatively, and not the positively excited body, is assumed to have the excess of the electric fluid. Others still further modify this theory by assuming electricity to be due to differences in the pressure of the universal ether, a kind of imponderable matter that is assumed to exist everywhere, and through which heat and light are propagated by means of vibrations or waves. These hold that positive electrification consists in an excess of the ether pressure, and negative electrification in a deficit of such pressure. We will not, however, discuss modern theories any further at this time. Later in the book, when a more intimate acquaintance has been obtained with the varied phenomena of electric science, we will be able to discuss electric theories in a more intelligent manner.

Modification of single-fluid theory.

Theory of differences of ether pressures.

But whatever the theory of electricity may be, this much is agreed by all, that what is produced by any electric source is not electricity, but a variety of force called the electro-motive force, which means electricity moving force. The friction of any two substances produces an electro-motive force, and this electro-motive force sets the electricity, whatever it may be, in motion. The word electro-motive force is for convenience generally contracted thus, E.M.F. The practical unit of E.M.F. is called the volt, after Alexander Volta, a prominent electrician of whom we shall speak hereafter. Its value is approximately equal to that of a single ordinary blue-

Electric sources produce E.M.F.'s, not electricity.

The volt or practical unit of E.M.F.

stone voltaic cell, of the form so commonly employed in telegraphy.

High E.M.F.'s produced by friction.

The E.M.F.'s produced by friction are so high that they are capable of causing electricity to pass through a circuit whose resistance is very great, and even to jump across an air gap, or interval separated by an air space. It can be shown that to cause a discharge or electric spark to pass through an air space one inch in length requires an E.M.F. of, approximately, 80,000 volts. In lightning flashes, therefore, the E.M.F.'s must be enormously high.

CHAPTER III

ELECTROSCOPES—ELECTROMETERS—ELECTRO-STATIC INDUCTION OR INFLUENCE

"He (Gilbert) calls it a versorium—in modern terms, it is an electroscope—made of a light metal rod, centrally poised on an apex like the needle of a compass."—*The Intellectual Rise of Electricity:* PARK BENJAMIN.

IN order to determine whether or not a body is electrified, an instrument called the electroscope may be employed. The electric pendulum, already described in connection with Fig. 2, is a simple form of electroscope, since the approach of an electrified body causes an attraction of the pendulum. When used to determine the character of a charged body, whether positive or negative, two balls are preferably employed, and the instrument may then be called the pith-ball electroscope. Such an electroscope is shown in Fig. 7. Here the balls are suspended by linen threads to some insulating support. When touched with a silk-rubbed glass rod, they each receive a positive charge and instantly repel each other and fly apart. When in this condition the approach of the excited glass rod causes them to fly still further apart. If such balls, therefore, while repelled by a charge of a known name, are approached by a body the character of whose charge is unknown, we can determine the character of this unknown charge by observing the movements of the balls: for, if they move further

Pith ball electroscope.

apart, the charge is positive, but if they are attracted or move together, the charge is negative.

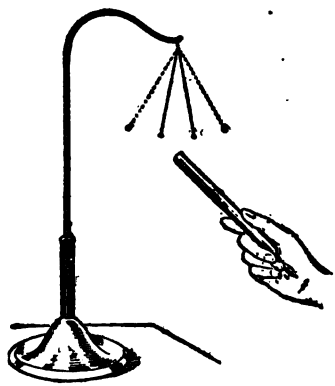


FIG. 7.—Pith Ball Electroscope. The pith balls are hung on linen threads which conduct the electricity from one pith ball to the other, but the pith balls are insulated by attachment to a glass support. A charge, therefore, imparted to one ball instantly spreads over the surface to the other ball.

Gilbert's needle electroscope.

A simple form of electroscope consists of a needle-shaped rod of dry wood provided with a cup at its middle part and suitably balanced on a needle-shaped support, as shown in Fig. 8. Such a needle is read-

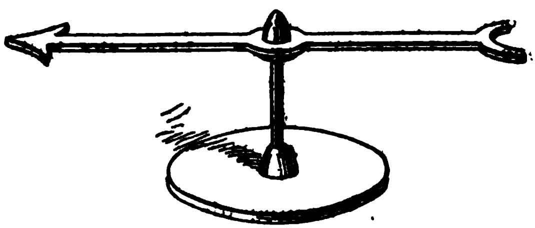


FIG. 8.—Gilbert's Versorium, or needle-shaped electroscope, the earliest form of the instrument.

ily attracted by exceedingly weak charges. This was the first electroscope ever constructed—Gilbert's versorium. Gilbert evidently shaped its form after that of the mariner's compass.

The form of electroscope called the gold-leaf electroscope, shown in Fig. 9, is still more sensitive. Here two narrow strips of gold leaf are attached to the end of a brass rod, provided at its upper end with a smooth brass ball, *c*. The rod and its attached leaves are placed inside an air-tight glass bottle, B, so as to protect the gold leaves and exclude moisture. This electroscope is so sensitive that its

Fig. 9.—Gold-leaf Electroscope. Note that the leaves diverge, although the excited rod does not touch the ball, *c*.

gold leaves are repelled by an electrified glass rod while several feet distant. In dry weather, merely walking briskly over a thick carpet will so charge one's body that the leaves will diverge by approaching a finger to the brass ball. A dry piece of wood is so charged by mere cutting with a pen-knife, that the chips will cause the leaves to diverge quite appreciably. Like any other electroscope, it can be employed to determine the kind of charge, whether positive or negative.

Gold-leaf electroscope.

When it is desired to measure the amount of the force with which the attraction or repulsion acts,

an instrument called Coulomb's torsion balance is sometimes employed. This instrument, as shown in Fig. 10, consists of a slender needle of shellac, *p*, at one end of which is a small gilt ball, *n*, so suspended by a very thin silver wire, within a glass cage, that it can move or swing in one direction on twist-

Coulomb's torsion balance.

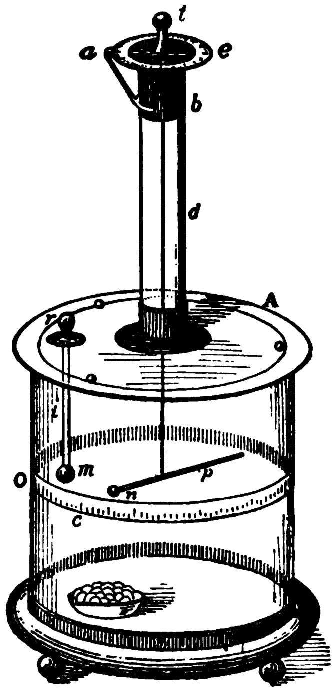


Fig. 10.—Coulomb's Torsion Balance.

ing the silver wire, by turning a supporting button, *t*, to which the wire is attached. Another insulated gilded ball, *m*, called a proof-plane, is attached to a glass rod, *i*. The proof-plane is provided for carrying to the instrument the charge to be measured. The body whose charge is to be measured is touched by the proof-plane, which immediately takes off a part

Proof-plane, use of, in torsion balance.

of its charge. The proof-plane can then be readily introduced into or removed from the cage, through a small opening in the top, and is of such a length that when in place the ball, *m*, is at the same height as *n*. To use the apparatus, the wire is carefully twisted until the two balls, *n* and *m*, just touch each other. The proof-plane is then withdrawn, charged by touching it to the body whose charge is to be measured, and reintroduced into the cage. The ball, *n*, is thereupon charged, and instantly repelled, coming to rest at an angular distance from *m* (measured by degrees marked on the side of the glass cage) by an amount depending on the charge in *m*. The amount of the charge is then ascertained by means of calculations based on the force required to untwist the wire. In order to keep the air inside the cage dry, a small bowl containing some substance like calcium chloride, that has a marked power to absorb moisture, is placed inside the cage. By means of this balance Coulomb demonstrated that the force exerted by any two electric charges, the distance between them remaining the same, is directly as the product of the charges, and inversely as the square of the distance between them. This law of inverse squares is only true when the charges are collected at points, or when the balls, *n* and *m*, are so small that, compared with the distance between them, they can be regarded as mere points.

Force of electric repulsion. How calculated.

Law of inverse squares. When true.

The quadrant electrometer is a more reliable and sensitive instrument. A simple form of this instrument is shown in Fig. 11. Without entering into a full description, it will suffice to say the instrument takes its name from the fact that the attracting and repelling plates have the form of quadrants, being shaped by cutting a circular plate into four equal parts. The quadrants are supported below a light

Quadrant electrometer.

aluminium needle, suspended, as shown, by a fine wire. The quadrants neither touch one another nor the needle, but the quadrants directly opposite each other are connected by conducting wires, 1 and 3, and 2 and 4, as shown at the top of the inclosing glass cage. If the connected pairs of quadrants are given positive and negative charges, in any

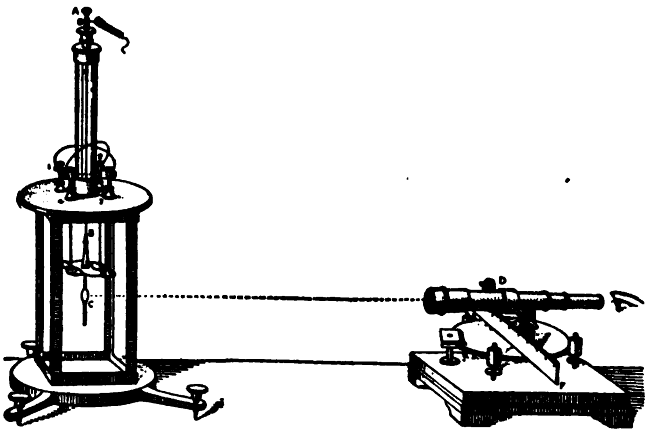


FIG. 11.—Quadrant Electrometer. The three levelling screws, on which the instrument rests, are provided to obtain a true level so as to cause the spot of light reflected from the mirror to fall properly on the scale.

Use of mirror in quadrant electrometer.

suitable manner, as by being connected to the terminals of a voltaic cell, the needle, when given a known small charge, is deflected to an extent dependent on the value of the charges imparted to the quadrants by the cell. In order to render the indications of the needle more sensitive, its movements are read through a telescope, D, on a scale, F, by means of a spot of light reflected from a small mirror, C. This instrument is sufficiently delicate to indicate a difference of potential as small as the $\frac{1}{10}$ of a single Daniell's cell.

We know that any uncharged insulated conductor can readily receive an electric charge by touching it with a charged insulated conductor. Suppose, for example, that the insulated conductor, C, Fig. 12, is brought into contact with the uncharged insulated conductor, A B, then the charge on C at once spreads over the surface of A B, as shown by the repulsion of all the pith balls, leaving both conductors positively charged. Since the charge on C is now spread over both C and A B, the electric density, or the quantity of electricity per unit of area, say per square inch or

Electric density, definition of.

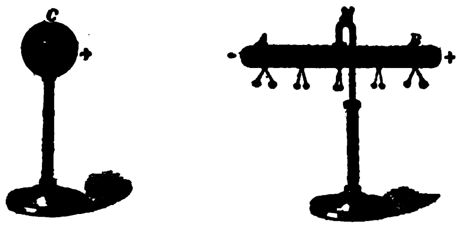


FIG. 12.—Electro-static Induction. Note the position of the pith balls as showing the difference in the distribution of the charge on A B.

square centimeter, will necessarily be less; the case being not unlike the more homely one of a quantity of butter, originally spread over a slice of bread whose area is, say, equal to that of C, being subsequently respread over both C and an additional slice having an area equal to that of A B. Electric charges received by actual contact are said to be imparted by conduction.

Electric charges by conduction.

We must now speak briefly of an electric current, by which we mean the rate at which electricity is passing through any conducting path or circuit. We can express this rate by stating the amount of electricity which passes through the circuit in a given time, say in one second, just as in a similar manner

Electric current.

we can speak of a flow or current of water in a pipe, as being equal to so many cubic inches, or so many quarts of water per second. The flow of water through a pipe is due to a water-moving force, and the quantity which flows in a second depends both on the amount of this force and on the dimensions of the pipe—*i.e.*, the resistance the pipe offers to the passage of the water through it. The flow of electricity through a circuit is due to an electro-motive force, and the amount of the flow is dependent both on the value of the electro-motive force and the dimensions and character of the circuit—*i.e.*, on the electric resistance, or the resistance the circuit offers to the flow of electricity through it. If the electro-motive force is one volt, and the resistance is one ohm, then the current, or rate of flow, is such that a quantity of electricity equal to one coulomb will pass through the circuit in one second. The practical unit of electric quantity is called the coulomb, after Coulomb, the inventor of the electric torsion balance.

Analogue of electric current and flow of water.

Practical unit of electric current.

Practical unit of electric quantity.

Ampère.

The practical unit of electric current is called the ampère, after Ampère, a distinguished French electrician. The ampère is equal to a rate of flow of one coulomb per second, and is the current which flows through a circuit whose resistance is one ohm, under an E.M.F. of one volt.

But, coming back to the insulated conductors shown in Fig. 12, we will now show how A B can receive a charge from the charged insulated conductor C, without coming in contact, and without C losing any of its charge. This is effected as follows: Supposing A B to possess no charge; if C, while charged, say, positively, be brought near to A B, but without touching it, the mere neighbor-

hood of C will produce a charge in A B, as will be indicated by the repulsion of the pith-ball electroscopes. This charge is developed across the air space between C and A, by what is called electro-static induction, or influence (discovered by Canton in 1753). The induced charge is strongest at the extremities A and B, as shown by the greater repulsion of the pith balls at these points than elsewhere, while at the middle of A B the charge is entirely absent. Moreover, if tested by any suitable means the charges at the ends will be found to be of opposite names, that at A, nearest the inducing positive charge, being negative, and that at B, furthest from the inducing charge, positive. The positive inducing charge in C has, therefore, acted across the intervening space and attracted a negative charge to A, and repelled a positive charge to B.

Electro-static induction or influence.

If the insulated conductor, A B, be removed from the influence of C, the two opposite induced charges will reunite and neutralize each other, and the conductor will cease to show any evidence of electrification.

Neutralization of opposite charges.

If, however, the conductor be made of two readily separable halves, which are separated while under the induction of C, each half will become permanently charged, the half that includes A being negatively, and the half that includes B being positively, charged or electrified.

Permanent charge produced by induction.

If, while under the influence of C, the conductor be touched by another conductor C will become permanently charged negatively.

If the positive charge on C be fairly great, the opposite or negative charge induced at A is correspond-

Different methods of obtaining permanent charges by induction.

ingly great, and if C is gradually approached toward A, the opposite charges will increase until finally a discharge takes place between A and C, in the form of a bright flash or spark.

How a gold-leaf electroscope is charged by induction.

We can now understand that when, say, a positively electrified glass rod is approached to the knob of the gold leaf electroscope shown in Fig. 9, its leaves are repelled by a positive charge. If the ball is touched by the hand while under the influence of the glass rod, a positive charge is repelled to the earth, and, on withdrawing the glass rod, the leaves are repelled by a negative charge. It is safer thus to charge the gold leaves by induction, since they are apt to be broken by the force of the repulsion if actually touched by a strongly excited body.

Induction the cause of the attraction of unelectrified bodies.

We can now also understand why an electrified body attracts an unelectrified body. Let the positively charged insulated conductor A, Fig. 13, be brought near the uncharged pith ball B. The pith

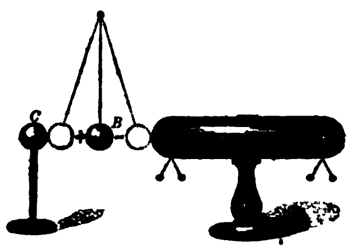


FIG. 13.—Cause of Electro-static Attraction and Repulsion. Note that attraction is preceded by induction, and that subsequent attraction is preceded by the loss of the induced charge by the body discharging to earth.

ball is at once electrified by induction; the side nearer the inducing body becoming oppositely charged, the ball is at once attracted to the conductor. As soon

as it touches the conductor it is charged with electricity of the same name as the conductor, and is at once repelled, and will remain repelled until it loses its charge. If, however, as shown in the figure, it is repelled until it touches an earth-connected body, such as C, it at once loses its charge, and will be again attracted and repelled, and alternate attractions and repulsions will be repeated for a fairly long time.

The chime of electric bells shown in Fig. 14 is Chime of electric bells.

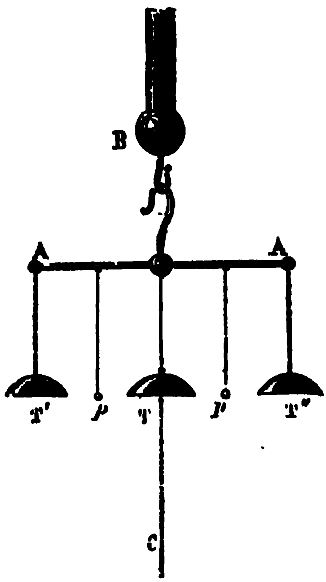


FIG. 14.—The Electric Chime. Note the fact that T' and T", as soon as charged by conduction from B, charge the clappers, *p*, *p*, by induction and cause them to strike the outside bells. Then being repelled they strike the middle bell, discharge through the chain, C, to ground, and are again attracted, etc.

operated by the alternate electric attractions and repulsions of the silk-suspended clappers, *p*, *p*. The

two outside bells, T′ and T″, are in metallic connection with the horizontal metallic bar AA, connected to a charged body B. The middle bell, T, is suspended by a silk thread, but is connected with the earth by a metallic chain, C. The successive attractions and repulsions of the clappers will cause a ringing of the bells as long as the body to which they are connected remains charged. It is interesting to note that this particular apparatus was employed by Canton, in his researches on atmospheric electricity, to notify him as soon as his apparatus began to be charged by electricity from the atmosphere. This was accomplished by the ringing of the bells. Here the horizontal bar received its charge from the air, so that when the bells began to ring, Canton knew that his apparatus was being charged.

Canton's use of electric chime to indicate electric condition of the atmosphere.

We can now state the general law of electrostatic attraction and repulsion, namely: Electric charges of the same name repel one another; electric charges of opposite names attract one another. That is a positive charge repels another positive charge, a negative charge repels another negative charge, but a positive charge attracts a negative charge, and a negative charge attracts a positive charge.

Gray's discovery of attractive action of surfaces of charged bodies.

Stephen Gray, before referred to, as the discoverer of the conducting power of bodies, in order to determine whether the quantity of matter in a body affected its power of conduction, made two cubes of oak, one solid and the other hollow, and found, when he suspended them by insulating strings, that both possessed the same power of attraction. He, therefore, correctly inferred that it was the surface only of the cubes that attracted. It is now a well-known

fact that electric charges reside only on the outside surfaces of insulated conductors, and not within their mass. This can be demonstrated in a variety of ways.

Suppose, for example, as was first shown by Biot, that the insulated metallic sphere S, Fig. 15, be charged, and that the metallic hemispheres H H′, insulated by the glass rods M M′, and just large enough to cover S, be then approached and brought

Biot's sphere.

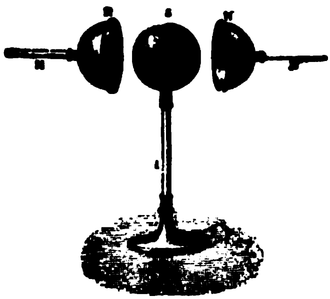


FIG. 15.—Biot's Sphere. The metal hemispheres H H′ fit the sphere S so closely as to come in good electric contact and thus increase its diameter to the extent of their thickness. The charge then instantly spreads to the outer surface of the enlarged sphere.

together while touching the sphere S. Instantly, all the charge leaves S and spreads over the outside surface of the hemispheres, and, when drawn away from S, they will be found to be excited, while S has no charge at all. The hemispheres are charged only on the outside. A proof-plane touched to the inside, immediately after their withdrawal, fails to affect a gold-leaf electroscope.

No charge on inside of hollow charged sphere.

The absence of any charge on the inside of a hollow insulated conductor is shown in Fig. 16, where

No charge on inside of hollow charged cylinder. the insulated metallic cylinder, provided with pith balls both on the inside and the outside, only shows,

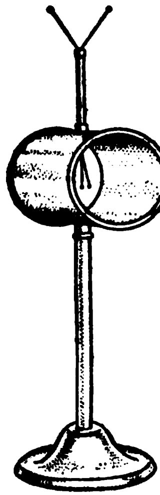


Fig. 16.—Hollow Insulated Metallic Cylinder. Note that although the pith balls connected to the outside show the presence of a charge there, those attached to the inside are unaffected.

by their repulsion, the presence of a charge on the outside when the cylinder is connected to an excited body.

CHAPTER IV

ELECTRIC MACHINES

"This experiment ocularly shows that the sulphur globe, having been previously excited by rubbing, can exercise likewise its virtue through a linen thread an ell or more long, and then attract something."—*Experimenta Nova:* VON GUERICKE. Amsterdam, 1672.

MACHINES for producing electro-static charges are of two kinds; viz., frictional machines and induction or influence machines. Frictional machines are either cylinder or plate machines. **Frictional electric machines.**

The first electrical machine was made in 1675, by Otto von Guericke, the inventor of the air pump. This machine consisted of a globe of sulphur rotated by suitable means against the friction of the hands. The globe was formed by pouring sulphur in a glass globe, subsequently breaking the glass when the sulphur had solidified. The sulphur globe was replaced by a globe of glass by Newton. Newton, describing his frictional electrical machine, says: **Guericke, Boyle and Newton.**

"A globe of glass about eight or ten inches in diameter being put into a frame, where it may be swiftly turned round its axis, will in turning shine when it rubs against the palm of one's hand applied to it; and if at the same time a piece of white paper or a white cloth, or the end of one's finger, be held at the distance of about a quarter of an inch or half **Newton's frictional machine.**

an inch from that part of the glass when it is in motion, the electric vapor which is excited by the friction of the glass against the white paper, cloth or finger, will be put into such an agitation as to emit light, and make the white paper, cloth or finger appear lurid like a glow-worm, and in rushing out of the glass will sometimes push against the finger so as to be felt. And the same things have been found by rubbing a long and large cylinder of glass and amber with a paper held in one's hand, and continuing the friction till the glass grew warm."

Boze, Winkler, Gordon, Franklin and Ramsden's contributions to frictional electric machine.

In 1741, Boze introduced in tne globular electric machine a conductor called a prime conductor. This consisted of a suitably insulated iron tube. In the same year, Winkler, of Leipsic, substituted a cushion of leather instead of the hand. Gordon, in 1742, used a glass cylinder in place of a glass globe. The

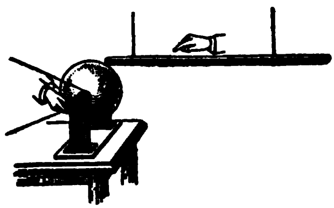


FIG. 17.—Early form of Globular Electric Machine. Note the globe as being one foot and a half in diameter. The hands are applied for friction.

comb of points employed as collectors was added after Franklin's investigations on the power of points in discharging electrified bodies. The substitution of glass plates for glass cylinders was made by Ramsden in 1760. Some idea of the appearance and proportions of one of these early forms of globular machines may be seen from an examination of Fig. 17.

SUSPENDED ELECTRIC RAILWAY

Trips are made from Loschwitz, a town on the river Elbe near Dresden, to the top of Rochwitz Heights, traveling a very steep grade. The same principle, applied on another German road, has resulted in very fast time

The cylinder electric machine assumes a variety of forms. That shown in Fig. 18, is a common form. A single cushion C, formed of leather stuffed with horse-hair, and covered with an amalgam of mercury and tin, was placed in electric connection with the insulated conductor A, and pressed firmly against the glass cylinder. On the opposite sides of the cylinder there is placed a similar insulated conductor B, provided with a comb of points P, that Cylinder electric machine.

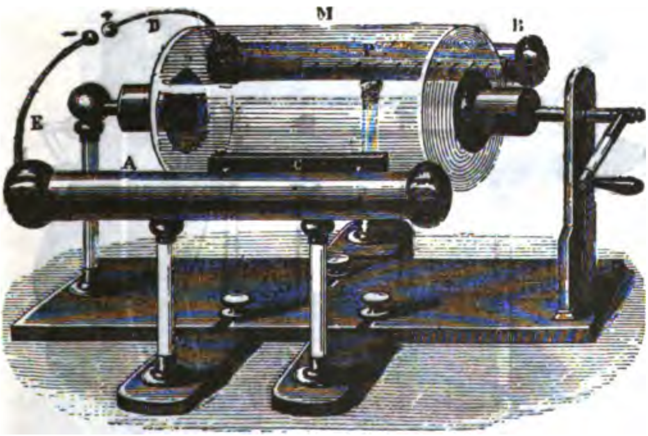


FIG. 18.—Cylinder Electric Machine. This is an old form of machine, now but seldom used. Note the fact that the prime or positive conductor is connected with the comb of points and the negative conductor with the rubber.

almost touch the glass. In practice, a piece of oiled silk, not shown in the figure, extends over the top of the cylinder from the rubber nearly as far as the points. By the rotation of the cylinder the conductor A, connected to the rubber, is charged with negative electricity, and the conductor B, sometimes called the prime conductor, with positive electricity. When the machine is in use either the negative or the positive conductor is generally connected to the ground by means of a metallic chain or conductor.

Explanation of action of frictional electric machine. It is not difficult to understand the action of this machine. The friction of the cushion produces a positive charge on the glass. As this charge, carried around by the rotation of the cylinder, comes opposite the comb of points it acts by induction on

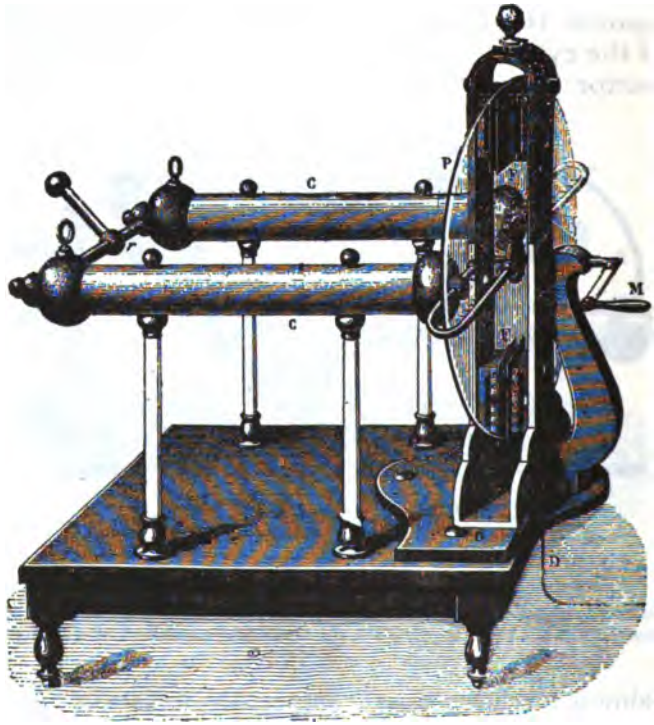


FIG. 19.—Plate Electrical Machine, although old, yet more frequently employed than the cylinder machine.

the prime conductor B, repels a positive charge to the far side and attracts a negative charge on the near side. This charge, being dissipated by the electric breeze, renders the charge on the glass neutral, thus making it ready to receive a new charge by friction, and leaves the conductor B, positively

charged. When properly acting fairly long sparks will pass between the polished brass balls + and —, connected respectively by bent conductors D and E with the positive and negative conductors B and A.

A well known form of frictional electric machine, commonly called the plate machine, shown in Fig. 19, consists of a circular glass plate, mounted so as to be capable of rotation by the handle M. Two sets of rubbers, F, F, are placed one above the other on opposite sides of the axis, as shown. These rubbers press on both sides of the plate. Two U-shaped brass rods, provided with a comb of points, are so supported that, as the plate rotates between them, they act on the charge generated on both sides of the glass plate by friction. Connected to these collectors are the prime conductors C, C, insulated by glass supports. The rubbers are connected with the ground by means of a metallic chain. Two pieces of oiled silk, not shown in the figure in order to permit the ready inspection of the different parts of the machine, are placed so as to extend each one-quarter way around from the cushion to the collecting points. **Plate electric machine.**

All electrical machines employing glass are liable to work poorly during damp weather, owing to a conducting film of moisture being deposited on the glass from the air. The surface of the glass should be kept clean and free from grease. Dust should be carefully removed, since each particle, acting as a point, tends to discharge the machine by means of connective discharges. **Care of electric machine.**

Before discussing induction machines, we will describe a form of frictional electric machine in which the charge is obtained by means of the friction of

globules of water against the sides of a peculiarly constructed wooden jet. Such a machine, Armstrong's Hydro-Electric Machine, is shown in Fig. 20. Here a wrought-iron cylindrical boiler, insulated by being mounted on four glass pillars, and provided, as is usual with steam boilers, with a water gauge, safety valve, and pressure indicator, fur-

Armstrong's Hydro-Electric Machine.

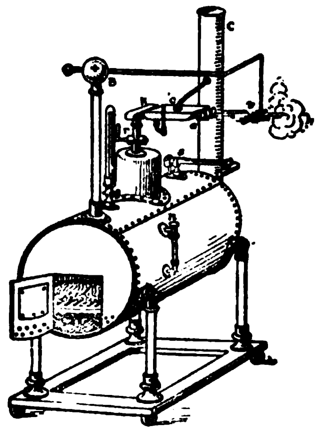


FIG. 20.—Armstrong's Hydro-Electric Machine, of scientific interest only. Dynamo-electric machines produce much more electricity and at far less expenditure of energy.

nishes the necessary steam. The steam produced is allowed to escape, through tubes of wood, over a vessel C, containing water, against a comb of points *v*, connected with the prime, or positive, conductor B. This machine is capable of producing a large quantity of electricity, though at comparatively high voltage. This quantity, however, is large only as compared with that produced by ordinary electric machines. As compared with the dynamo electric machines, the quantity is extremely small, but its E.M.F. is very high. It is necessary for the proper operation of this machine that the water be pure.

The presence of a small quantity of acid or saline substances renders the machine inoperative.

Another type of electrical machines are called influence or electro-static induction electric machines. These are so efficient in action, and so capable of working in nearly all kinds of weather, that they have almost entirely replaced the ordinary frictional machines. Before describing them we will describe the old form of induction apparatus called the electrophorus, produced by Volta in 1775. This is advisable, since all electro-static induction in influence machines depend for their operation on the principles of the electrophorus.

Advantages of influence or induction machines.

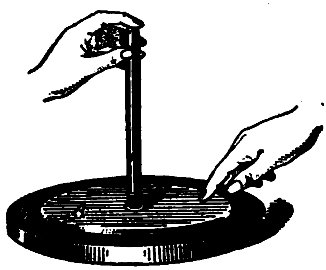


FIG. 21.—Electrophorus—Charging. The touched finger enables the plate to lose a charge of the same kind as the inducing resinous disk.

The electrophorus, Fig. 21, consists of a plate of vulcanite or a disk B, of some resinous material, such as a fused mixture of ordinary resin, shellac and turpentine, solidified in a metallic dish. A negative charge is imparted to this disk by briskly rubbing it with a piece of cat skin. An insulated metallic conducting plate, A, with smoothly rounded edges, but of smaller diameter than the resin disk, is now placed on the excited disk and touched by the finger. If now the plate A be lifted by the insulating handle, it will be found to be strongly elec-

Description of electrophorus.

trified positively, and sparks can be taken from it, as shown in Fig. 22. Meanwhile, the resinous disk will not be found to have lost any of its electrification, and the insulated disk may be charged again and again, care being taken to touch its surface each time before lifting it from the lower disk by the insulating handle.

Explanation of action of electrophorus.

The action of the electrophorus will now be readily understood. The negatively excited resinous disk acts inductively on the insulated conducting plate,

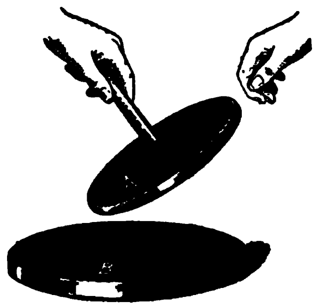


FIG. 22.—Electrophorus—Discharging. The discharge is of an opposite name to that of the resinous disk; viz., positive.

repelling its negative electricity to the ground through the body when touched by the finger, but holding the positive charge on the plate by attraction. On withdrawing the insulated plate, therefore, its charge being no longer bound, excites the plates positively.

Free and bound electricity.

It is evident from the preceding experiment, and from what we have already seen in the study of electro-static induction, that electricity exists in two states or conditions; viz., in a free state, as in the insulated conducting plate, when it is lifted from the inducing resinous disk, and in the bound state,

as it exists when held on the plate by the attraction of the opposite charge on the resinous disk. Bound electricity is sometimes called disguised or latent electricity. Strictly speaking, the electricity in all charges is bound to some extent, since, no matter where the body is, it tends to induce charges on all surrounding bodies through the intervening atmosphere or other medium. Still, it generally can readily be discharged by touching, and it is only when brought very near some inducing body that it can not be readily discharged. The terms are, therefore, convenient as describing these two different conditions.

Disguised or latent electricity.

Every influence or induction machine is, in point of fact, a form of a revolving electrophorus. Such machines depend for their action both on electrostatic induction and on the ability which two charged conductors possess of reciprocally augmenting each other's charge; or, as it is sometimes called, on the principle of reciprocal accumulation. Suppose, for example, that two insulated conductors, A and B, Fig. 23, possess each a slight charge, A a positive and B a negative charge, and that a third insulated conductor, called a carrier, be revolved so that it moves successively past A and B, during each revolution. Let us suppose that while it is moving past A, and is, therefore, under the inductive action of its positive charge, it is touched. It will, on being carried beyond the influence of A, possess a small free negative charge. Now let matters be so arranged that as it moves on, it is permitted to give this negative charge to B. If touched while under the inductive action of B, it acquires a small free positive charge as soon as it is carried beyond the influence of B, and moves on and gives this charge to A, thus augmenting its positive charge.

Two conditions on which action of influence machines depend.

Principle of reciprocal accumulation.

A now acts by induction more powerfully, and as the carrier continues to be revolved the charges on A and B go on accumulating. In this manner powerful charges can be built up from very weak initial charges.

Thompson's generalized type of induction machine.

Fig. 23, from S. P. Thompson, from whom this explanation of the principle of induction machines

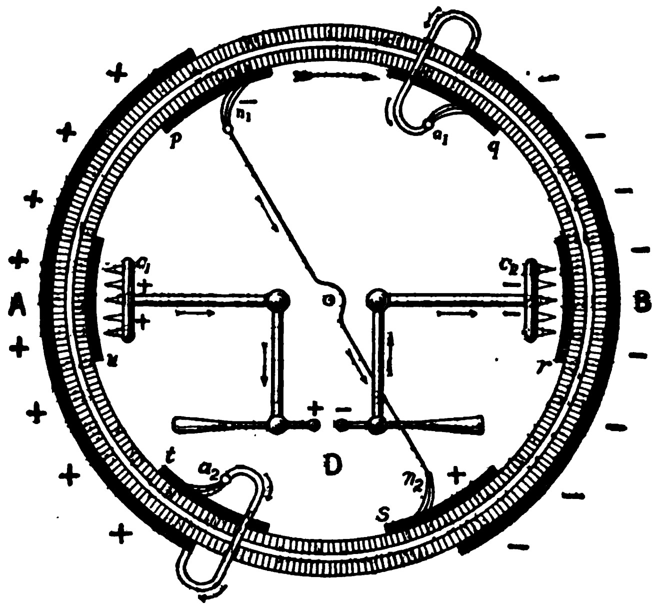


FIG. 23.—Generalized type of Electro-static Induction Machine.

is abstracted, represents a generalized type of induction machine, with two fixed field plates or conductors, A and B, which are to become respectively positive and negative, attached to a stationary glass cylinder. A set of six carriers, *p, q, r, s, t,* and *u*, are attached to the inside of an inner rotating cylinder. In addition to the above, a pair of neu-

tralizing brushes, n_1, n_2, formed of flexible metal wires, are provided to touch the carriers, while under the influence of the field plates. These brushes are connected electrically by a diagonal conductor as shown in the figure. A set of appropriating brushes, a_1, a_2, connected with the field plates, reach over from the field plates to collect the charges as they are conveyed by the carriers, and impart them to the field plates. Finally, there is provided the discharging apparatus, consisting of two combs, c_1, c_2, to collect any unappropriated charges from the carriers after they have passed the appropriating brushes. The combs are connected to a pair of discharging balls, capable of ready adjustment as to the distance between them. A pair of Leyden jars, not shown in the figure, is generally connected to the discharging rod.

Operation of induction or influence machines.

The operation of the machine may now be readily understood. Setting the neutralizing brushes so as to touch the carriers just before they pass out of the inductive action of the field plates, if the field plate A has a slight positive charge, which may be imparted to it, if necessary, by touching it by a positively excited body, then the carrier p, touched by n_1, at the moment it passes the field plate, acquires a small negative charge, which it carries forward to the appropriating brush a_1, thus making B slightly negative. Each carrier, as it is carried forward to the right and is touched by n_1, will do the same thing. On the lower side, as the carriers move from right to left, they are touched by the neutralizing brush n_2, while under the induction of the negative charge on B. They therefore carry a small positive charge to A, by aid of the appropriating brush a_2. In this way the field plate A is rapidly made more and more positive, and the field plate B more and

more negative, and consequently the more do the collecting combs, c_1 and c_2, receive the unappropriated charges. Torrents of thin, blue sparks, therefore, pass across the air gap between the discharging knobs at D, with a sharp hissing sound if the Leyden jars are not connected, but with a sharp snap or report and bright spark if such jars are connected. To ensure proper action both the neutralizing and the appropriating brushes must make good electric contact with the carriers.

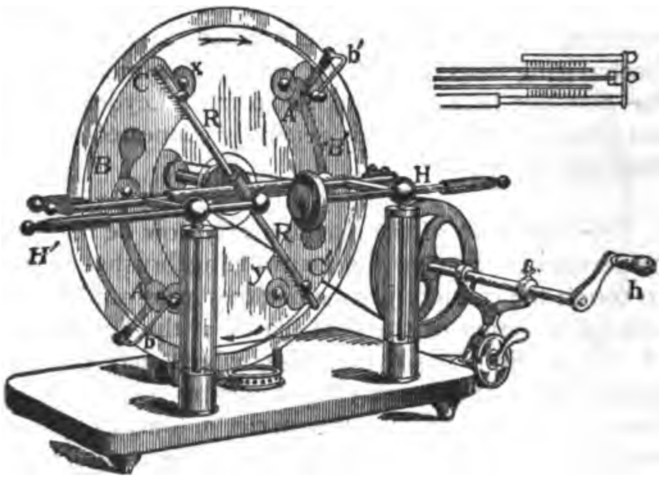


FIG. 24.—Töppler-Holtz Induction Machine. An excellent form of electrostatic induction or influence machine.

Töppler-Holtz Induction Machine. The Töppler-Holtz Machine is a form of influence or induction machine that operates in accordance with the above general explanation. It is made either with a single or with several revolving plates. That shown in Fig. 24 consists of three plates of glass covered with shellac varnish. One of these plates is fixed and the other two are so mounted on a shaft as to be capable of being re-

volved. The fixed plate carries two pieces of tin-foil, A B C, and A′ B′ C′, each of which is protected by a covering of shellacked paper. These constitute the two field plates. The rotating plates carry a number of small disks of tin-foil cemented to their front faces. These constitute the carriers.

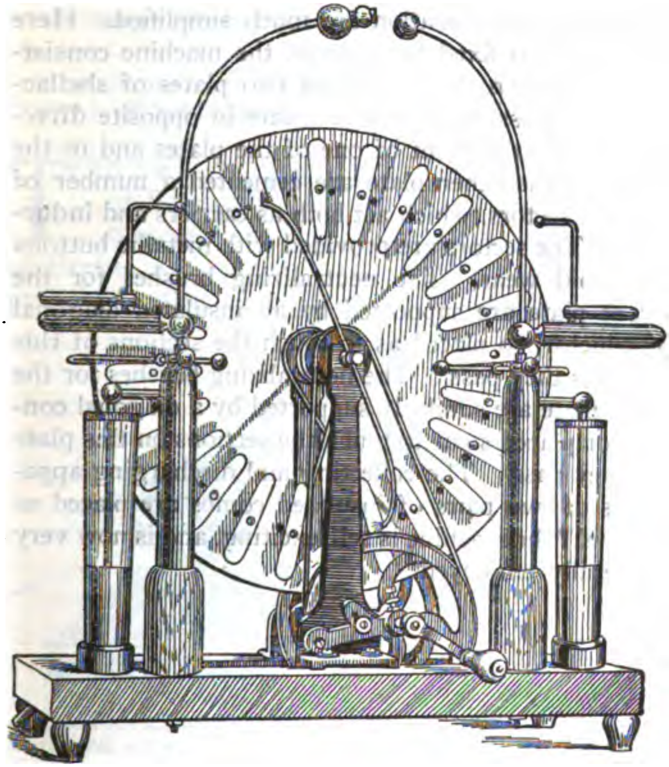


FIG. 25.—Wimshurst Electro-static Induction Machine. Probably one of the most efficient electro-static induction machines.

Metal buttons are provided at the centres of the disks to prevent the disks of tin-foil from being worn by the friction of the brushes. The neutralizing brushes are connected by the diagonal conduc-

tors. The appropriating brushes, *b* and *b′*, are clamped to the edge of the fixed disk. The combs, placed as shown, are connected to the adjustable discharging rods, H, H′, mounted on two small Leyden jars.

Wimshurst Influence Machine. In the Wimshurst Influence Machine, the construction and operation are much simplified. Here there are no fixed field plates, the machine consisting, as shown in Fig. 25, of two plates of shellac-covered glass, arranged to rotate in opposite directions. To the front of one of the plates and to the back of the other plate are cemented a number of tin-foil sectors, which act both as carriers and inductors. The sectors are provided with metallic buttons to avoid wear. The neutralizing brushes for the front plate are supported by an insulated diagonal conductor, so placed as to touch the sections of this plate as they pass. The neutralizing brushes for the back plate are similarly supported by a diagonal conductor placed so as to touch the sections on this plate as they pass. The collecting and discharging apparatus of two pairs of insulated combs are placed as shown. The machine is self-exciting, and is now very generally employed.

CHAPTER V

VON KLEIST AND THE LEYDEN JAR

"I would not take a second shock for the Kingdom of France."—MUSCHENBROECK, *in a letter to Reaumur.*

TOWARD the close of 1745, Von Kleist, Bishop of Pomerania, desiring to isolate electricity, conceived the idea of leading a charge from an electric machine into a glass bottle, arguing, in all probability, that he might in this manner be able to

Von Kleist's invention of the Leyden jar.

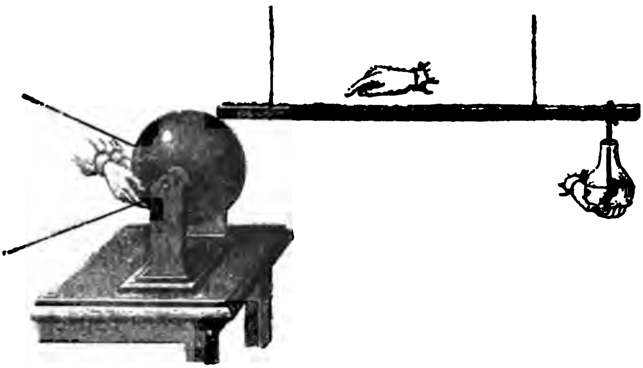


FIG. 26.—Von Kleist's discovery of the Leyden jar. Note the objectionable sharp angles and edges of the prime conductor. This was before the discharging power of points or sharp edges was known.

fill the bottle with electricity, since he imagined the electricity would not be able to escape on account of the non-conducting property of the glass. With this end in view, he partially filled a small glass bottle with water, and, holding it in one hand, con-

nected its inside to the conductor of an electric machine by means of a bent wire that passed through the mouth of the bottle and reached down below the surface of the water, attaching the wire to the machine, as shown in Fig. 26. As will be readily understood, by these arrangements Von Kleist had produced a Leyden jar, the water inside the bottle forming the inner coating, and the hand supporting it, the outer coating.

Von Kleist's account of electric shock.

Von Kleist did indeed succeed in obtaining a bottle filled with electricity; for, when endeavoring to remove the charged bottle from the machine, in order carefully to examine its contents, he received a shock, which, although necessarily slight, considering the size and character of the apparatus, was nevertheless unduly exaggerated by his terror. In a letter sent to a scientific friend in Berlin, dated November 4, 1745, he says of the bottle: "If while it is electrified I put my finger or a piece of gold which I hold in my hand to the nail, I receive a shock which stuns my arms and shoulders."

Cuneus and Muschenbroeck, and the Leyden jar.

The honor of the invention of the Leyden jar is ascribed by some to Cuneus, of Leyden, a pupil of Muschenbroeck, and by others to Muschenbroeck himself. The discovery by both of these is said to have been made in a similar manner. Muschenbroeck's surprise at receiving the shock was even greater than Von Kleist's. In a letter to Reaumer he says: "I felt myself struck in my arms, shoulders and breast. I lost my breath, and it was two days before I recovered from the effects of the blow and the terror."

Origin of name of Leyden jar.

The Leyden jar received its name from the city of Leyden, where Cuneus lived, most probably, be-

cause he gave greater publicity to its peculiar effects than Von Kleist did.

These experiments created intense excitement in scientific circles in all parts of Europe. Despite his assertion to the contrary, Muschenbroeck, in common with other scientific men, spent a large part of his time in repeating and modifying the experiment. 1745 and 1746, were, therefore, memorable in the annals of early electric history. Apart from their scientific interest, these early experimenters appeared to have derived a morbid satisfaction from what they alleged were the terrible effects of the subtle agency. Allamand, on taking a shock, said: "I lost the use of my breath for several minutes, and then felt so intense a pain along my right arm that I feared permanent injury from it." Winkler says, referring to the first time he made the experiment, "I suffered great convulsions through my body; it put my blood into agitation; I feared an ardent fever, and was obliged to have recourse to cooling medicine." Boze, whom we have already recorded as the inventor of the prime conductor of the frictional electric machine, even went as far as to assert that he coveted electric martyrdom, so that the account of his death might found an article for the Memoirs of the French Academy.

Exaggerated accounts of physiological effects of Leyden jar shocks.

Despite these foolish misgivings, numerous investigations were made, and the Leyden jar was greatly improved. Bevis, in 1745, substituted coatings of tin-foil for the water and the hand. In the same year Watson, Smeaton, Wilson, Canton, and others still further improved the jar.

Improvements in Leyden jar.

Some idea of the excitement in scientific circles, created by the invention of the Leyden jar, may be

gained from the following quotation taken from Cavallo's "Electricity," already previously quoted from. This was a book printed in 1795, by Tiberius Cavallo, and contained, in some three volumes, a fairly full description of the comparatively little that was then known concerning electricity. To the mind of Cavallo, however, this little appeared so great that he questioned whether, in view of so much having been accomplished during 1745 and 1746, there could be reasonable hope for electricians in the future making any new discoveries. He apparently feared that 1746 had seen the discovery of practically all the world ever could hope to know concerning the electric force. However, his better judgment prevailed, and, as will be seen from the quotation, he conceded that the young electrician might still have a vast field before him in the future. Could Cavallo have but lived in our days, he would appreciate the fact that this prediction was much truer than he probably believed.

Extract from Cavallo's "Electricity."

"In short, nothing contributed to make Electricity the subject of the public attention, and excite a general curiosity, until the capital discovery of the vast accumulation of its power, in what is commonly called the Leyden phial, which was accidentally made in the memorable year 1745. Then, and not till then, the study of Electricity became general, surprised every beholder, and invited to the houses of Electricians a greater number of spectators than were before assembled together to observe any philosophical experiments whatsoever.

Effect of invention of Leyden jar on electric progress.

"Since the time of this discovery, the prodigious number of Electricians, experiments, and new facts that have been daily produced from every corner of Europe, and other parts of the world, is almost in-

credible. Discoveries crowded upon discoveries; improvements upon improvements; and the science ever since that time went on with so rapid a course, and is now spreading so amazingly fast, that it seems as if the subject would be soon exhaused, and Electricians arrive at an end of their researches; but, however, the *ne plus ultra* is, in all probability, as yet at a great distance, and the young Electrician has a vast field before him, highly deserving his attention, and promising further discoveries, perhaps equally or more important than those already made."

The discovery of the Leyden Jar, for it should properly be called a discovery rather than an invention, was, indeed, a matter of the greatest importance to electric science. And yet the Leyden jar is so exceedingly simple in its structure that one would hardly expect that it possesses such marvellous powers. It is a mere glass jar, coated both on the outside and inside with tin-foil, with a good length of free space left between the mouth of the jar and the upper edge of the tin-foil. But, connect the inner coating with the prime conductor of an ordinary electric machine, so feeble that it can scarcely produce sparks one-sixteenth of an inch in length, and place the outer coating in connection with the ground, and turn the handle of the machine. The jar will then manifest its peculiar power of accumulating electricity; for the feeble machine, aided by this powerful device, is now able to produce charges far in excess of what it would be able to do without the Leyden jar.

Simplicity of the construction of the Leyden jar.

The Leyden jar, as left by these early investigators, consisted, as shown in Fig. 27, of a jar of glass, coated over the outside and inside up to about two-

Description of Leyden jar.

thirds of its height with tin-foil. In the top of the jar is placed a cork or lid of dry wood, through

FIG. 27.—Leyden Jar. Here the dielectric is of glass and the opposite coatings of tin-foil.

which passes a rounded knob, A, of polished brass connected to a brass chain, E, that communicates on the inside with the tin-foil coating.

Leyden-jar battery, advantages of over single large jar.

Where a very powerful charge is required, a single large jar may be used, but it is more convenient to use a number of smaller jars, placed in a box, the inside of which is lined with tin-foil, so as to connect all the outside coatings of the separate jars, while the insides are connected as one large jar, by means of brass rods, as shown in Fig. 28, thus practically forming a single Leyden jar. Such an arrangement is called a Leyden-jar battery. In the figure the battery is represented as having been charged from the prime conductors, C^1, C^1, of the electric machine, represented at the left hand side of the figure. The battery is represented in the act of being discharged through some substance placed at F, by means of discharging rods held in both hands as shown at the upper right hand side of the figure. In the case of a Leyden-jar battery, should the electric stress pierce the glass of one of the jars, the entire battery will not be rendered useless.

Besides this, a much thinner glass can be safely used when a number of smaller jars are connected

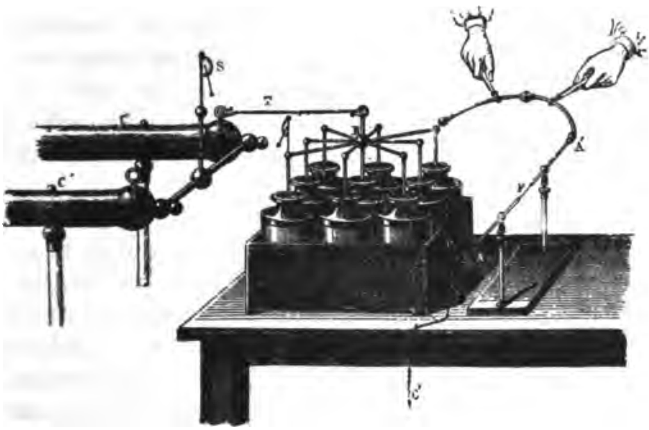


FIG. 28.—Leyden-Jar Battery. Note how the discharging tongs are employed. The device at S is a form of electrometer known as Henley's quadrant electrometer. Here the name quadrant was given from the shape of the graduated scale used to measure the angular deflection.

so as to form a single jar than if one single large jar were employed, and this permits a greater induction to take place through the thinner glass.

Let us now inquire as to the action of the Leyden jar. To do this we will first give some attention to what is called the electric capacity of a conductor. **Electric capacity of conductor.** By this is meant the quantity of electricity that must be imparted to such conductor in order to electrify it to a certain degree; or, in other words, to give it a certain electro-motive force. A large conductor, for example, would require a much greater quantity of electricity to give it an E.M.F. of one volt than would a smaller conductor.

In order to understand how the quantity of electricity charged on a conductor can affect its E.M.F.,

Electric level or potential.

we will inquire briefly into the idea of electric level, or electric potential. It is convenient, at times, to compare some of the simpler effects produced by electricity with the analagous action of ordinary liquids. This is all right, provided we keep constantly in mind that, although we are well acquainted with the laws in accordance with which electricity acts, yet we do not really know what electricity is.

Difference of water level or potential.

If a vessel be filled with a liquid, say water, there is thereby produced a water-pressure, or water-motive force, that causes the water to tend to move from this vessel to another vessel, with which it communicates by means of a pipe. This motion, however, can never take place if the level of the water is the same in both vessels. It is only when the water level is higher in one vessel than it is in the other that a flow or current occurs. Now the height of the liquid in either vessel, its capacity or size being fixed, depends on the quantity of water in the vessel; and its ability to flow or pass from one vessel to the other depends on the difference of level, and this difference of level is called the potential.

Difference of electric level or potential.

In a similar manner a given quantity of electricity raises the electric level of a conductor to an extent dependent on the capacity of the conductor. A positive charge in a conductor corresponds to a higher electric level, and a negative charge to a lower level than when unexcited. The difference of electric level, or electric potential, therefore, results in an electric pressure, or E.M.F., which causes the electricity to tend to flow, the flow, as in the case of liquids, taking place from the higher to the lower level. The capacity of a conductor, therefore, may

be measured by the quantity of electricity required to produce, by the establishment of a certain difference of electric level, or potential, an electric pressure, or E.M.F., which tends to cause an electric flow from the higher to the lower level. Electric pressure or E.M.F.

The practical unit of electric capacity is called the farad, in honor of Faraday, the great electrician. Since the practical unit of electric quantity is the coulomb, and the practical unit of E.M.F. is the volt, the farad may be defined as that capacity of a conductor which requires a quantity of electricity equal to one coulomb to produce in it an E.M.F. of one volt. Since a condenser whose capacity is one farad would require to be enormously large, in practice, a smaller unit, called the micro-farad, whose value is equal to the one-millionth of a farad, is generally employed. The farad or practical unit of electric capacity. The micro-farad.

The Leyden jar is able to take such comparatively large charges because the electric capacity of a conductor is markedly increased by placing it near another conductor possessing an opposite electric charge. The Leyden jar is sometimes called a condenser. Since a Leyden jar accumulates a greater charge than would be possible were it not for the proximity of the closely approached plates, it was formerly called an accumulator. This term accumulator is now reserved for the storage battery, a device which will be subsequently described. Electric condenser. Electric charge accumulator.

The operation of the Leyden jar can be best understood from an examination of the condenser of Æpinus, constructed in 1759. This condenser consists, as shown in Fig. 29, of two insulated metallic plates, A and B, capable of being moved toward Condenser of Æpinus.

and from each other, with a plate of glass, C, placed midway between them.

Explanation of action of condenser.

Let us suppose that while it is too far from A to be affected by its inductive action, B be connected to the positive conductor of an electric machine. It will continue to receive a positive charge until its charge is equal to that of the machine. The electricity will then cease to flow from the machine to B, because the electric level or potential is the same on both conductors. The charge on B will now be spread equally over both surfaces of the conductor. If, under these circumstances, B be moved toward C,

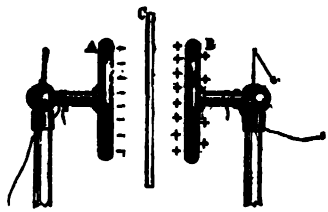


Fig. 29.—Condenser of Æpinus. Note the greater electric density of the positive charge, received from the machine on the surface of the conductor B, nearer the charging machine than on the side nearer the plate A. This increased density is indicated by the greater number of plus signs.

How the charge accumulates on a condenser.

the charge on B will act inductively on A, and repel a positive charge from A to the earth, through the conducting wire shown, and cause a negative charge to accumulate on the side of A that is nearest to B. At the same time, the mutual attraction between the positive charge on B, and the negative charge on A, will cause the charge of B to collect mainly on the side B, nearest the machine, and causing its electric potential or level on the other side of B, to fall below that of the machine. Consequently, a further flow of positive electricity will be able to pass from the machine to B, which again

acts inductively on A, and again accumulates an additional charge on the side nearer to A. In this manner, the charge goes on accumulating, the capacity of either A or B, under these circumstances, being markedly greater than it would be if they stood alone.

The insulating substance, separating the two conductors, which permits the induction to take place through its mass, is called a dielectric. All insulators are capable of acting as dielectrics, but to an unequal degree. The following are a few dielectric media; viz., air, glass, shellac, sulphur, gutta-percha, insulating oils, and a vacuum. The ability of a dielectric to permit induction to take place through its mass is called its dielectric capacity, or its specific inductive capacity. The amount of electricity which can be accumulated on the plates of a condenser depends on the potential of the conductor, on the area of the plates, on the thickness of the dielectric separating them, and differs with the character of the substance, that is, with its dielectric capacity.

Dielectrics.

Dielectric capacity or specific inductive capacity.

Circumstances determining the charge that can be accumulated on a condenser.

The Leyden jar acts in the same manner as the condenser of Æpinus. The opposite metallic coatings form the conductors, and the glass of the jar the dielectric. While charged, either of the coatings can be safely touched without discharging it, since each charge is held in place or bound by the attraction of the opposite charge. But, if both coatings are simultaneously touched by a conductor, the jar will practically be instantaneously discharged. If this is done by touching one coating with the right hand, and the other coating with the left hand, a severe shock will be felt, the intensity of which will depend both on the size of the jar and on the amount of the charge.

Explanation of the action of a Leyden jar.

Discharging Tongs.

A convenient and safe method of discharging the Leyden jar is by means of the discharging rods, which consist of two bent brass rods terminated by blunt balls of brass, provided with glass insulating handles, and hinged so as to permit the distance be-

FIG. 30.—Dissected Leyden Jar. Remember that it is the glass dielectric whose surfaces retain the opposite charges. The conducting coatings merely convey the charges to all parts of the surfaces of the glass to which they are attached.

tween the free ends to be readily varied. A pair of discharging rods, in the act of discharging the Leyden-jar battery, are shown at the upper right hand side of Fig. 28.

Dissected Leyden jar.

During his study of the Leyden jar, Franklin showed that, contrary to what was formerly believed, the charges are not accumulated on the opposite metallic coatings, but on opposite sides of the dielectric. This fact can be demonstrated by means of the dissected Leyden jar—*i.e.* a jar the coatings of which can be readily detached. Such a jar is shown in Fig. 30. If this jar is charged when the coatings are in place, they may then be separated by lifting A out of the glass jar and then removing the outer coating B, being careful to touch only one coating at the same time. Thus separated, no charge will

SEWING MACHINE OPERATED BY AN INDUCTION MOTOR

For many women a mechanically operated sewing machine will be a veritable blessing. This problem, now solved by electricity, puzzled inventors for a long time. Hydraulic power has been tried, and also coiled springs, to provide motive power for the machine

be found in either of the coatings, which may be freely handled, and connected to the earth, or placed in contact with each other. The charges are on the outer and inner surfaces of the glass. If the different parts of the jar be again assembled, as at the right hand side of the figure, a strong spark may be drawn from the jar by means of the discharging rod. The charge resides, therefore, in the dielectric medium separating the two oppositely charged conductors.

Charge of Leyden jar on opposite surfaces of dielectric only.

The comparatively large capacity of condensers causes them to be used in a variety of apparatus. They may either take the form of the ordinary Leyden jar, or they may take a more compact form in which numerous separate sheets of tin-foil are separated by very thin sheets of mica or paraffined paper. The separate condensers, formed by each sheet of paraffined paper and its opposing coatings of tin-foil,

Form of standard condenser.

FIG. 31.—A Standard Condenser of the capacity of a microfarad or the one-millionth of a farad.

and connected together into a single large condenser, as the separate Leyden jars in a Leyden-jar battery are connected into a single Leyden jar. On the top of the box are placed binding posts, the two outside posts being connected respectively to the two opposite coatings, and the middle post being provided in order to readily discharge its condenser,

by connecting its opposite coatings. A common form of such condenser is shown in Fig. 31. Condensers of a capacity of but one-third of a microfarad require about 1,200 square inches of tin-foil.

Residual charge.

A single discharge of a Leyden jar does not completely remove all its charge. If the jar be left to itself for a short time after its first discharge, a second discharge may be obtained, though, of course, much feebler than the first. This discharge is due to a residual charge produced by a penetration of the charge into the substance of the glass or other dielectric. The liberation of the residual charge is hastened by gently tapping the glass.

CHAPTER VI

THE LUMINOUS EFFECTS OF ELECTRIC DISCHARGES

"Castor and Pollux came afterwards to be considered the patron deities of seamen and voyagers, and the lambent flames which, in certain states of the atmosphere, play round the sails and masts of the vessels, were called by their names."
—*The Age of Fables:* BULFINCH.

THE effects produced by electric discharges may be divided into a variety of classes, the most important of which are luminous effects, or those attended by the production of light; thermal effects, or those attended by the production of heat; mechanical effects, or those observed frequently in the case of either non-conductors or partial conductors, in which the substances are pierced, torn or broken; chemical effects, in which either combinations or decompositions of chemical substances take place; magnetic effects, in which magnet poles are produced or reversed by the passage of the discharge; and physiological effects, or those attending the passage of electric discharges through the bodies of animals or plants. All the above effects are produced, to some extent or other, by electric discharges, no matter what their source may be. We will at present discuss the effects of such electric discharges only as are produced by frictional electric machines or influence machines, or by the discharge of Leyden-jar batteries, in all of which cases very high electro-motive forces are involved.

Classification of effects produced by electric discharges.

High electro-motive force discharges.

Some of the luminous effects produced by discharges of high electro-motive force were noticed

Guericke and the first electric light.

early in the history of electric science. Guericke had no sooner produced his globular electrical machine than he noticed, during its action, the production of an electric glow or light. This is the first electric light of which we have any record. It was exceedingly feeble, and compared but unfavorably with the bright light now so common in all parts of the civilized world. In its way, it was not unlike the feeble effects produced by Thales in the case of the rubbed amber. Like its predecessor, it has grown to the remarkable proportions it possesses to-day.

Electric spark.

If the knuckles of the hand be held near a highly charged conductor, such, for example, as the prime

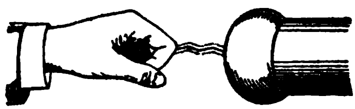


FIG. 32.—Disruptive Discharge or Spark Passing Between Charged Conductor C and Hand. Remember that in all such cases opposite charges accumulate by electro-static induction or influence on the opposed surfaces, and that when these are sufficiently powerful the dielectric, in this case the air, is broken and the spark passes.

conductor C, shown in Fig. 32, a bright spark will pass between the conductor and the hand.

The appearance of the spark between any two approached bodies depends on a variety of circumstances. If the discharging surfaces consist of blunt metallic balls, that are separated but a short distance, the discharge is marked by a slender but very bright line. As the distance between the discharging sur-

Branching, zig-zag or lightning-like discharges.

faces increases, the spark assumes an irregular form, having a somewhat zig-zag appearance or shape, as shown in Fig. 33. The irregularity of this path is generally explained by the discharge taking the path

of least electric resistance, and this being determined by the presence of dust particles in the intervening air. The irregularities in the path of the discharge are also due to the compression of the air in front of it, the discharge taking by preference the less dense air on one side or the other. Faraday showed, in his researches, that, during induction between two conductors, a polarization takes place in the intervening dielectric. As soon as the tension or stress produced on this line of polarized particles has reached a certain degree of strength, a breaking down or disruption occurs in the medium, and the spark passes. Such discharges are, therefore, generally called disruptive discharges.

Faraday, and the polarization of the medium through which the discharge passes.

The size of the conducting surfaces between which the discharge occurs also affects the appearance of

FIG. 33.—Branching Disruptive Discharge between Discharging Surfaces. Note the similarity in the appearance of the discharge to the forked or so-called zig-zag lightning flashes. Note here that one of the discharging surfaces is smaller than the other.

the electric spark. Where both surfaces have the form of large spheres, and are not very far apart, the sparks are very brilliant, taking a straight path, and are accompanied by loud detonations. If, however, the area of the sphere attached to the prime conductor is small, as compared with that of the

Influence of size of conducting surfaces on appearance of spark.

opposing surface, the spark assumes the irregular path, characteristic of ordinary lightning. The light is far less brilliant as the length of the path of the discharge is increased, its intensity, in all cases, depending on the quantity of electricity passing. This is only another way of saying that the brilliancy of the spark depends on the very high temperature to which the discharge has raised the intervening particles of the air or other medium through which it is passing.

Electric sparks colored by vaporized metallic particles torn from conductors.

During disruptive discharges small portions of metal are torn from the conductors that form the metallic surfaces between which the discharge is passing. These particles, vaporized by the intense heat produced by the discharge, impart to it characteristic colors; for example, copper and silver give a green color to the spark. Iron imparts a reddish color. That these colors are due to vaporized metallic substances is shown by an examination of the light by means of an instrument called the spectroscope, an apparatus for determining the chemical nature of any substance which is heated high enough to change it into an incandescent or glowing vapor, by an examination of the different colored lights it emits. In this case the spectroscope reveals the presence of colored lights, due to glowing vapors of the same metals as those forming the surfaces between which the discharge is passing.

Spectroscopic examination of spark.

Color of spark affected by kind of medium through which it passes.

The nature of the medium, through which the spark is passing, also affects its color. In air, at ordinary pressures, when the volume of the discharge is great, the spark has a bluish-white color. Thin discharges passing through a greater length of air are somewhat purplish in tint, and are frequently of unequal luminosity in different parts of their length,

being much darker in places where the quantity of electricity passing is small. In nitrogen, the spark is the same color as in air, except that it is of a deep blue or purple tint. In hydrogen, the spark assumes a beautiful crimson color.

If the distance between the discharging surfaces is increased so far that a disruptive spark or discharge is unable to occur, the discharge spreads itself in the form of a faintly luminous, divergent brush of the blue color characteristic of the passage of a slender discharge through air. The intensity of this light is so small that it can be seen only in a dark room. Such discharges are called brush discharges, and are attended by a crackling, hissing sound. **Brush discharges.**

Brush discharges are not continuous. As Wheatstone has shown, they consist of a number of successive partial discharges that follow one another at very rapid intervals. Their intermittent character is also shown by the fact that the hissing noises have a more or less definite pitch, like musical notes, and that, as the distance between the discharging surface is decreased, the pitch of the musical notes becomes higher, that is, the notes become shriller. **Intermittent character of brush discharges.**

The brush discharge consists of numerous separate streams branching out from a main trunk or stem. Each of these separate streams divides, or branches into numerous smaller streams, not unlike the rivulets and rills that unite to form the larger streams in a river system. The breadth of the brush discharge is increased by holding a flat plate a short distance from the extremity of the luminous portion of the brush. The same effect is produced by holding the **Appearance of the brush discharge.**

palm of the hand in a similar position. The brush discharge shown in Fig. 34 will give an excellent idea of the general appearance of this form of discharge.

When the area of the electrified surface is reduced to a mere point, or when the electrification is increased beyond a certain point, the brush discharge

FIG. 34.—Brush Discharge from Van Marum, who employed an electric machine of very great power. The machine had the revolving glass plate sixty-five inches in diameter.

Glow or silent discharge.

changes into the glow discharge. Here the musical note is absent, the discharge being continuous and not intermittent, like the brush discharge. The glow discharge takes its name from the fact that a faint glow of phosphorescent light accompanies it. In the glow discharge the electric charge appears to be carried off the conductor by means of a stream of air particles that are violently thrown off the surface of the conductor. This motion of the air particles is due to their repulsion from the charged conductor, which takes place as soon as, by coming in

Cause of motion of air in glow discharge.

contact with the conductor, they receive from it an electric charge. The amount of electrification required to produce the glow discharge is decreased by decreasing the density of the air through which the discharge is passing.

The glow discharge is sometimes called a convective discharge, for the reason that the motions it sets up in the surrounding air somewhat resemble the convection streams or air currents set up in the air around a heated body, by means of the difference in the density of the surrounding air. The glow or convective discharge is sometimes called the silent discharge, in order to distinguish it from the noisy disruptive discharge.

Convective discharge.

A negatively charged conductor produces a differently shaped discharge from a positively charged conductor. When intermittent discharges are tak-

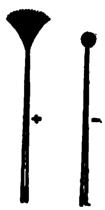


FIG. 35.—Characteristic appearance of the brush discharge produced by a positively charged conductor, and the star discharge produced by a negatively charged conductor.

ing place from a negatively charged conductor, they generally assume the shape of a star discharge instead of the characteristic brush-shaped discharge from positively charged conductors. The difference in the appearance of the positive brush discharge and the negative star discharge is shown in Fig. 35. Faraday has shown that these differences are due

Difference in appearance between the positive and the negative discharge.

to the fact that a negative charge escapes more readily into the air than an equal positive charge.

Manner of obtaining spark, brush and glow discharges from machines.

All the three forms of luminous discharges above described—viz., the spark, the brush, and the glow—can be readily obtained from an ordinary induction machine, such as the Töppler-Holtz, or Wimshurst induction machine, by properly arranging the discharging balls or other terminals, provided for discharging the machine. Placing the discharging balls at the proper separating distance, bright sparks follow one another with a rapidity depending on the rate at which electricity is being produced by the machine. On placing Leyden jars in the circuit, brilliant white sparks occur, but at less frequent intervals than when the Leyden jars are absent. If the balls are separated beyond the distance at which the spark discharge occurs, the hissing and more or less musical brush discharge takes place. If the balls are replaced by points, under suitable conditions, the silent glow discharge occurs.

Composite or multiple discharges.

If, while a brush discharge is taking place between a ball or sphere connected with the positive conductor and a plate connected with a negative conductor,

FIG. 36.—A Multiple Discharge resulting, under certain conditions, from the breaking of a single discharge into a number of approximately parallel separate discharges.

the terminals are brought near together, the brush discharge takes the shape of a number of more or less parallel separate discharges, such as are shown in Fig. 36.

It should be carefully borne in mind that in any of the preceding luminous electric discharges taking place in air or other medium, it is not a stream of electricity that becomes visible along the path of the discharge, but a stream of particles of the air or other substance constituting the medium, through which the discharge is passing, that have been rendered incandescent or luminous by the heat produced by the passage of the electricity.

Light of sparks due to glowing air, gas, or vapor.

The length of the disruptive discharge between two opposed conductors depends primarily upon the difference between their electric potentials. It varies markedly with the pressure of the air or other gases through which the electricity passes, increasing rapidly as this pressure decreases. In other words, it is easier to pass a discharge through a partially vacuous space than through air at ordinary pressures. The length of spark also varies in different gaseous media, being about twice as long in hydrogen at ordinary atmospheric pressures as in ordinary air. A convenient method for observing the color and other peculiarities produced by the passage of the discharge through different gaseous media consists in placing the gases in sealed glass tubes provided with platinum wires for leading the discharge into and out of the tubes. The different gaseous substances within such tubes may either be at ordinary atmospheric pressures, or may be in a partially rarefied state by exhaustion by means of an air pump, before the tubes are sealed by the melting of the glass.

Circumstances affecting length of sparks.

Gaseous discharge tubes.

High-potential discharges, when passed through partial vacua, produce luminous phenomena, which differ markedly in appearance with the degree of exhaustion. If a tube or other inclosed glass vessel,

filled with ordinary air, be connected with an air pump while disruptive sparks are passing, a change will be observed in the appearance of the discharge, as the inclosed space becomes more and more rarefied by the removal of the air. At the beginning of the exhaustion the sparks lose their sharp definition; then they gradually increase in width until they occupy the entire inclosed space. This change is accompanied by a change in their color. They no longer possess the bright light of the disruptive spark, but take on the appearance of a pale phosphorescent glow, and assume the characteristic blue or purple color already referred to.

Discharges in partially exhausted gases.

As the exhaustion of the glass vessel continues, the phosphorescent glow, instead of filling the entire space, takes a curious form of alternate patches of light and shade, giving the space a striated or stratified appearance. This luminous phenomenon is called the stratification of the electric discharge. As the exhaustion continues, the dark spaces between the alternate luminous bands increase in width, and the volume of the discharges decreases, until, at very high degrees of exhaustion, the discharges entirely cease to pass, even if the difference of electric potential between the terminals be greatly increased, or the distance between the discharging points is greatly decreased.

Stratification of the electric discharge.

The curious fact exists, therefore, that, as regards its conducting power, air, at ordinary pressures, is a good insulator; that while, at gradually decreasing pressures, its insulating powers are markedly decreased, becoming as it does at moderately high degrees of exhaustion a fairly good conductor, yet at very high vacua air becomes an almost perfect insulator. This fact is of interest when taken

Insulating powers of a high vacuum.

in connection with the electric charge of the earth. The earth, as is well known, moves around the sun in a space that is practically devoid of all ordinary matter; or, in other words, in an extremely high vacuum. Any electric charge, therefore, imparted to the earth is thus effectually prevented from being lost or dissipated, at least as far as anything outside the earth is concerned. A glass tube orovided with

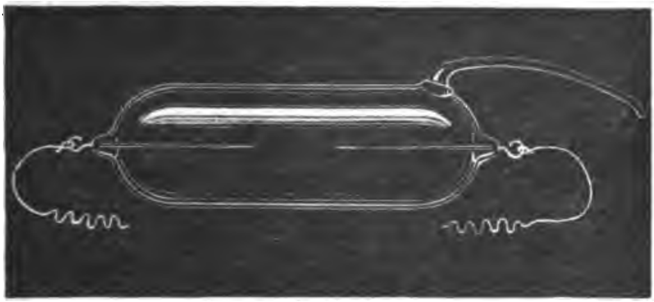


FIG. 37.—Glass tube containing a high non-conducting vacuum. Note the leading-in platinum wires. The glass projection at the upper right-hand corner, is where the tube was connected to the air-pump. This tube, was, however, subsequently sealed by the melting or fusion of the glass.

closely approximated conducting wires of platinum, and containing the non-conducting vacuum, is shown in Fig. 37. When the platinum wires are connected with the terminals of a machine capable of causing sparks to pass freely through an inch or more of air, the sparks absolutely refuse to pass, thus showing that a high vacuum is a very much better non-conductor than is air at ordinary pressures. High vacuum tube.

In order to be able to readily produce electrical striæ without being compelled to obtain the proper degree of exhaustion each time this effect is desired, stratification tubes are prepared. These consist, as shown in Fig. 38, of glass tubes provided with lead- Stratification tubes.

ing-in wires or conductors, the tubes are filled with various gaseous substances and are then exhausted until the desired stratification effects are produced, when they are permanently sealed by the fusion of the glass.

De La Rue on the cause of the stratification of the electric light.

Much study has been given to the cause of electric striæ. De la Rue asserts that the striæ begin at the positive terminal in the tube, and move forward through the tube toward the negative terminal. This

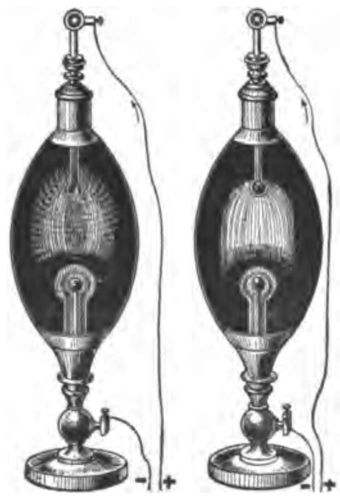


FIG. 38.—Stratification Tubes. Note the alternate striæ.

fact can be established by the examination of the striæ by intermittent flashes of light. The striæ increase in number with an increase in the degree of vacuum, and also with an increase in the difference of potential between the discharging points. The luminous portions of the striæ are of a higher temperature than the dark portions.

The cause of the striæ has been attributed by some to an interference between rapid successive

discharges, but it is not clear just how such interferences take place. Gassiot regards the striæ as possibly being due to luminous waves produced during the discharge, and believes the dark portions are due to nodes, or points of no motion, similar to the nodes observed in the vibration of a stretched string or wire.

In order to readily obtain some of the beautiful effects produced by electric discharges in partial vacua, Geissler and others have produced thin glass tubes and bulbs of various shapes, provided with metallic leading-in wires and terminals, and filled with various gaseous substances. The tubes are exhausted while the electric discharges are passing, and, when the desired luminous effects are obtained, exhaustion is stopped, and the tube is hermetically sealed by the melting of the part connected to the pump. This method is much handier than endeavoring to obtain a vacuum of a definite degree of exhaustion each time the tube is desired to be used; for luminous effects of different characters depend on a variety of circumstances. It is advisable, however, when this method of procedure is adopted, to be careful to employ as nearly as possible the same difference of potential between the terminals of the tube as is likely to be employed in practice. These tubes are generally named Geissler tubes, from Geissler, who first produced them.

Geissler tubes.

Fluorescent substances employed in Geissler tubes.

In order to increase the beauty of electric discharges through Geissler tubes, all or parts of the tube are sometimes made of uranium glass. Glass containing uranium possesses the power of fluorescing, or causing some of the radiant energy produced during the discharge, that would otherwise be invisible to the eye, to be so changed that it is able to

produce a beautiful green light. Similar effects are also produced by introducing fluorescent liquids, such as sulphate of quinine, a substance which fluoresces with a purplish or bluish light.

Phosphorescent substances employed in Geissler tubes.

In the same way different luminous effects are produced by placing in Geissler tubes various phosphorescent substances; *i.e.*, substances which possess the power of becoming self-luminous when exposed to a bright light. Calcium and barium sulphides, sugar, and various compounds of uranium are some substances that possess this power. Besides increasing the beauty of the luminous effects, while the discharge is passing, such tubes will continue to glow, in

FIG. 39.—Electric Phosphorescence produced by the passage of disruptive discharges between the terminals P and N. Such a tube contains a fairly high vacuum.

a dark room, long after the discharges have ceased to pass. Such an effect is shown in Fig. 39, which represents an electric phosphorescence tube. Here the phosphorescent substances, barium or calcium sulphides, placed in the bottom of the tube, become beautifully self-luminous during the passage of a discharge between the terminals P and N. This same tube, long after the electric discharge has ceased to pass, will continue to glow in the dark, though, of course, not so brightly.

Electric phosphorescence tube.

The calcium and barium sulphides above alluded

to are the substances which are sometimes employed on match safes, or similar objects, as phosphorescent paints. On exposure to sunlight, any surfaces covered with such paints will continue to glow throughout the night with a faint phosphorescent light, and thus locate in a dark room the position of a match safe or other object. If painted on the face of a clock, it will give sufficient light to enable the time to be seen by one near to the clock without any other illumination.

Phosphorescent paints.

As we will be better able to understand further on in this book, when we have studied electro-magnetic phenomena, luminous electric discharges are curiously affected by the presence of magnets, altering either their position or shape on the approach of a magnet; or, in some cases, actually revolving around the magnet. These effects are somewhat similar to the action produced by magnets on readily movable electric conductors, when electric currents are passing through them.

Influence of magnetism on luminous discharges.

A form of apparatus designed to illustrate the luminous effects produced by electric discharges is shown in Fig 40. It is sometimes called, from its shape, the electric egg. It consists of a glass vessel provided with suitable terminals for the passage of the electric discharge. The lower end is furnished with a screw thread for ready attachment to the plate of an ordinary air pump. With this apparatus many of the luminous effects produced by the discharge can be readily obtained.

Electric egg.

A variety of pleasing luminous effects, produced by a series of small disruptive discharges, can be obtained by arranging various groupings of minute

Spark tube. discharge paths on glass surfaces. This is accomplished by fastening small particles of tin-foil on the surface of the glass, and leaving short intervening air gaps or spaces between adjacent pieces. By caus-

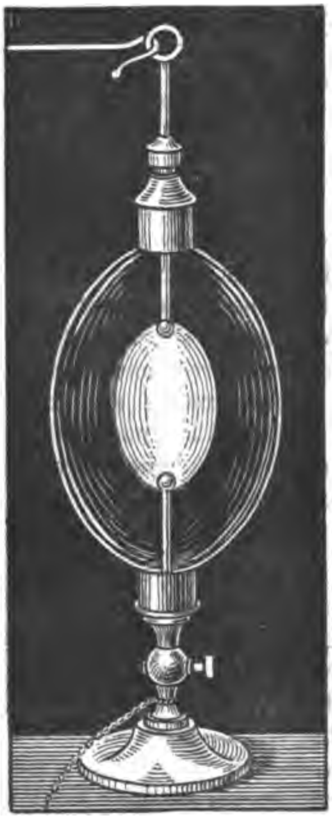


FIG. 40.—The Electric Egg. A glass vessel provided for producing luminous effects by the passage of discharges through partial vacua. Note that the upper rod can be slid toward or from the lower rod, thus varying the length of the path of the discharge.

ing high-potential discharges to pass from one end of such paths to the other, brilliant flashes of light

occur at the air spaces, across which the charge passes disruptively, but no light is produced at the places occupied by the patches of tin-foil. A glass tube so arranged is shown in Fig. 41

It is very easy to obtain similar effects by placing pieces of tin-foil on sheets of glass, arranged so as to form the outline of a figure or design. In the same way names can be produced, together with a variety of other effects. The separate pieces of foil may either be placed one after another on the glass, or, which is perhaps easier, the entire surface of the glass intended to be occupied by the picture may be covered with a single sheet of tin-foil, and the breaks

Electrically luminous picture.

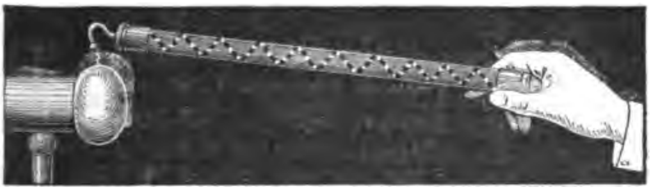


FIG. 41.—A spark tube arranged to produce flashes of light along a spiral path.

or air gaps, obtained by removing the foil at the necessary places. When arranged on glass places, it is always preferable to leave a fairly wide border or space unoccupied by foil, since, otherwise, excessive leakage might occur at the edges.

A device called the lightning jar, intended to illustrate the irregular path taken by lightning discharges, consists of an ordinary Leyden jar, the outer coating of which is formed by sprinkling brass filings over the surface while covered with moistened gum. When the gum dries, the filings adhere to the surface of the jar, and form the outer coating. When

Lightning jar.

such a jar is discharged a flash of light may be observed in a dark room, not unlike that of the ordinary so-called zig-zag lightning.

St. Elmo's fire, or the "holy body."

A variety of luminous phenomena, observed in the atmosphere, are caused by the passage through it of electric discharges. One of these phenomena, called the St. Elmo's Fire, occurs at times when the atmosphere is highly charged with electricity. It consists of faintly luminous brushes or tongues of fire that occur at the extremities of tall objects, such as the masts and yards of ships, the tops of church spires, at the ends of the branches of trees, and in other similar locations. These phenomena are due to a brush-like discharge of electricity from the points of the object into the air. The name St. Elmo's Fire was given to these appearances by some superstitious Spanish sailors, who believed the light to proceed from the body of their dead saint. For this reason they are often called by sailors corposants, the word referring to the body of the saint. The name has been retained in later days.

Pliny.

We have already noticed the fact that the similar luminous phenomena were referred to by Pliny, in his "Natural History." The Roman sailors hailed with special delight the appearance of two such luminous tongues, and called them Castor and Pollux, the gods whom they believed presided over navigators. When, however, but a single tongue of fire was observed, they regarded the phenomenon with dread, as signifying danger and misfortune. The following account of such phenomena is taken from De la Rive:

Castor and Pollux.

"In 1696, at anchor off the Balearic Isles, during very dark weather, accompanied by frightful lightnings and thunders, Forbin relates that they saw on

the ship that it was surmounted by more than thirty St. Elmo's fires; there was one in particular, on the top of the vane of the mainmast, which was half a yard in height. A sailor, having climbed to the top of the mast, related that the fire made a particular noise, which, according to the description that he gave of it, appeared to be in every respect similar to that which is made by electricity, when it escapes into the air under the influence of a powerful tension. The sailor, having removed the vane, immediately saw the fire leave it to transfer itself to the top of the mast. Many cases are cited, in which soldiers, especially cavalry (which is due to their being more elevated), have seen fires shining on the points of their lances and their swords. But it is especially in time of storm that these fires are seen on the summit of clock towers and of elevated places in general. Watson relates that M. Binon, curé of Planzel in France, observed for twenty-seven consecutive years that, during great storms, the three points of the cross of the bell-tower of his church appeared enveloped in flames. Although, in contradistinction, there are very elevated places that never present these appearances, it is probable that it is due to want of observation, their having in general been so little remarked upon the salient parts of ships, at the point of bell-towers, or upon the rods of the vanes, and the lightning conductors placed upon the summits of houses. Besides, a sufficient number of them have been observed to have enabled us to point out differences between these lights, not only in respect to their intensity, but also in regard to their forms; thus, although most frequently they resemble brushes, nevertheless it also sometimes happens that their light is found concentrated into a small globe, without any trace of diverging jets."

De La Rive's description of St. Elmo's fire on ship off the Balearic Isles

Observations of Binon, cure of Planzel.

Globular form of St. Elmo's fire.

Luminous phenomena of dry fog in Europe 1783.

De la Rive points out the fact that it is not only at the extremities of tall objects that such luminous phenomena appear. Sometimes objects on the earth's surface acquire this luminous appearance during the progress of storms. At times even the rain, snow, or hail emits a faint phosphorescent light or glow. During the famous dry fog of 1783, that covered the greater part of Europe, a diffused light, visible at night, occurred, which was sufficiently intense to enable one to distinctly see fairly near objects. Such luminous phenomena are generally attended by the peculiar hissing sound characteristic of the brush discharge.

Brewster on luminous electric phenomena on Mt. Etna.

Brewster mentions the case of two English travellers who were surprised during a descent of Mt. Etna by a heavy snowstorm. On this occasion, the air was so heavily charged with electricity that, in addition to frequent violent lightning flashes, they heard a hissing sound whenever they extended their arms in the air. The appearance of St. Elmo's Fire on the masts and spars of a ship is shown in Fig. 42. Usually only one or two such fires are seen on the spars at the same time.

Aurora Borealis and Australis.

But a far more beautiful phenomenon, frequently observed in the atmosphere at certain seasons of the year, is known as the Aurora Borealis when it occurs in the Northern Hemisphere, and the Aurora Australis when it occurs in the Southern Hemisphere. These phenomena are due to the passage of the electric discharge through the higher regions of the atmosphere, where the density of the air permits it to act as a fairly good electric conductor.

The Aurora takes its name from "aurora," or the morning hour, from the fact that the light seen near

the horizon at the beginning of the phenomenon presents an appearance not unlike the dawn of day. During its occurrence an auroral arch, or corona, as it is sometimes called, appears in the northern sky, with its highest part immediately under the position occupied by the north magnetic pole of the

Auroral arch or corona.

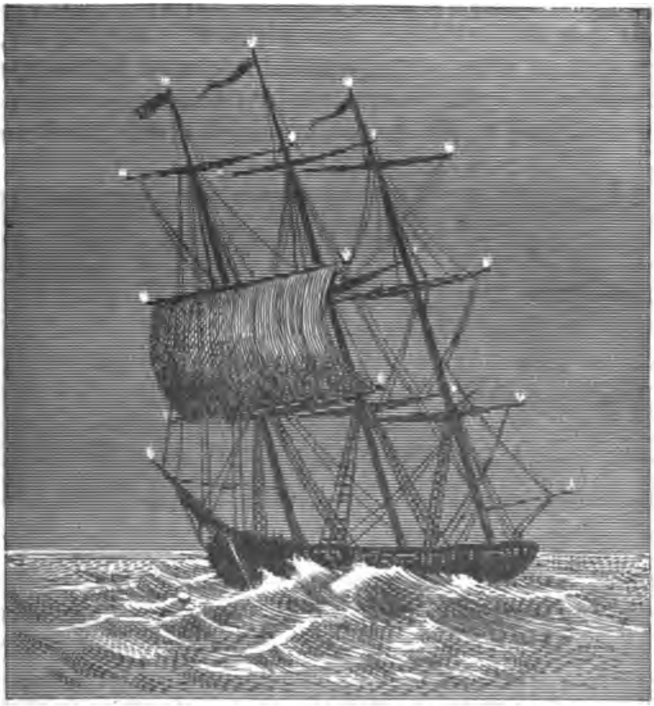


FIG. 42.—The appearance of St. Elmo's Fire on the masts and spars of a brig. Sailors call these appearances corposants, or holy bodies.

earth. The height which the arch occupies above the horizon is greater in higher latitudes—that is, in regions nearer to poles of the earth. As the aurora progresses, the corona gradually rises higher in the sky, and streams of light of varying colors

—white, red, and purplish, and even, on rare occasions, yellow and green—dart suddenly up through the arch. These movements are at times so rapid and irregular that in the Shetland Islands they are called the "Merry Dancers." The continually rapid movements in all parts of the aurora form an exceedingly characteristic feature of the phenomenon. Sometimes only a single streamer starts up, increases in size and brilliancy, moves rapidly over the sky, and fades away; or, a series of streamers follow one another in rapid succession. At times these movements give to the sky an appearance that has been

The merry dancers of the Shetland Islands.

Auroral streamers

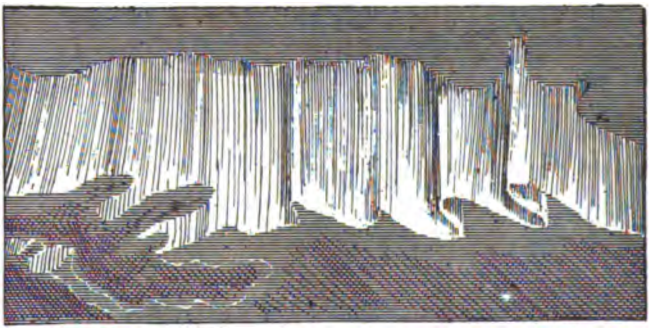


FIG. 43.—Magnificent Auroral Curtain seen on the coast of Finland, lat. 70° N. Note the resemblance to the folds of a ribbon.

very properly likened to the drifting of a luminous storm of snow or rain across the heavens. At other times a series of parallel rays in the form of a luminous curtain, or several curtains placed one behind another, extend across the sky from east to west. This is known as the curtain formation of the aurora. Fig. 43 shows the appearance of a single auroral curtain, observed on the coast of West Finland, lat. 70 degrees N., during the winter of 1838-39. The parallel rays of the curtain are clearly shown. A constant motion of the curtain occurred.

Auroral curtain.

AUTOMOBILE FITTED WITH WIRELESS TELEGRAPH APPARATUS

This movable telegraph station has been used to transmit stock quotations from the "Curb Market," in New York, to various brokers' offices. It is, of course, something of an oddity, built chiefly to show the possibilities of wireless telegraphy

The luminous rays not only appeared to move rapidly across the horizon, but they rapidly grew longer or shorter, changing very suddenly in splendor. The horizontal motion of the streamers gave the auroral curtain the appearance of a band of ribbon, or of a flag shaken by the wind, this being greatly aided by the color of the light, which was blood red at the base, emerald green in the middle, and pale yellow at the upper parts. At other times, an auroral band, consisting of a single streamer, extended across the heavens from east to west. The red glow observed during the progress of some auroras is at times so well marked that it has been mistaken for the glow of a distant conflagration.

Magnificent auroral curtain seen near the coast of Finland.

Corona and streamers.

The general appearance of an auroral corona, with the streamers, is seen in Fig. 44. The streamers

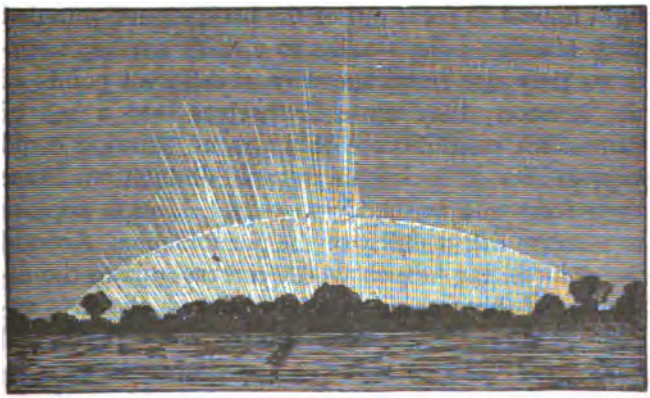


FIG. 44.—Auroral Corona and Streamers, seen at Paris, Oct. 3, 1882.

radiate from a centre situated behind the horizon. They differ in size, brilliancy and color.

The following description of an aurora was given by Humboldt in the "Cosmos":

Humboldt's description of phenomena of corona.

"An aurora borealis is always preceded by the formation in the horizon of a sort of nebulous veil, which slowly ascends to a height of 4°, 6°, 8°, and even to 10°. It is toward the magnetic meridian of the place that the sky, at first pure, commences to get brownish. Through this obscure segment, the color of which passes from brown to violet, the stars are seen, as through a thick fog. A wider arc, but one of brilliant light, at first white, then yellow, bounds the dark segment. Sometimes the luminous arc appears agitated for entire hours by a sort of effervescence, and by a continual change of form before the rising of the rays and columns of light, which ascend as far as to the zenith. The more intense the emission is of the polar light, the more vivid are its colors, which from violet and bluish white pass through all the intermediate shades to green and purple red. Sometimes the columns of light appear to come out of the brilliant arc, mingled with blackish rays, similar to a thick smoke; sometimes they rise simultaneously in different points of the horizon; they unite themselves into a sea of flames, the magnificence of which no painting could express; for, at each instant, rapid undulations cause their form and brilliancy to vary. Motion appears to increase the visibility of the phenomenon. Around the point in the heaven which corresponds to the direction of the dipping-needle produced, the rays appear to assemble together and to form the boreal corona. It is rare that the appearance is so complete, and is prolonged to the formation of the corona, but, when the latter appears, it always announces the end of the phenomenon. The rays then become more rare, shorter, and less vividly colored. Shortly nothing further is seen on the celestial vault than wide, motionless, nebulous spots, pale or of an ashy color; they have already disap-

Motions and colors of auroral light.

Appearance near termination of phenomenon.

peared, when the traces of the dark segment, whence the appearance originated, are still remaining on the horizon."

Height of aurora.

The height of the aurora has been variously estimated. The earlier observers believed that it was limited to the higher regions of the atmosphere, where the conducting power of the air is great. They founded this belief on the fact that apparently the same aurora could be simultaneously seen by observers some thousands of miles apart. More recent observers, however, believe that the phenomenon occurs in much lower regions. Dalton places their height at about 241 miles above the general level of the earth; Newton, at 130 miles; and Nordenskjöld, at from 118 to 125 miles. Still more recent observations place the phenomenon at no greater height than 69 miles.

Dalton and Nordenskjöld.

Geographical distribution of aurora.

As regards the geographical distribution of auroras, they are practically confined to comparatively narrow belts or zones. Auroras are unknown at the equator, and rarely occur in the Northern Hemisphere at latitudes less than 40 degrees. From this latitude their frequency and brilliancy increase toward the pole. It is not, however, in the immediate neighborhood of the pole that the greatest auroral activity occurs. In the chart shown in Fig. 45, of the Isochasmen lines, as the lines of equal auroral frequency are called, it will be seen that the number of auroras increases as we approach the pole, although, as before noted, the number is not greatest in the immediate neighborhood of the pole. It will be also noted that the Isochasmen lines do not have their centre in the north magnetic pole of the earth, but that this pole is situated considerably to one side of the centre. Of course, it must be remembered

Isochasmen lines, or lines of equal auroral frequency.

that such a chart is, at best, only an approximation toward the actual state of things, since the number of observations is as yet too limited to permit of any exact representation.

Nordenskjöld, who passed the winter of 1878-79 in Bering Strait, states that during that time he found the earth to be continually surrounded by a

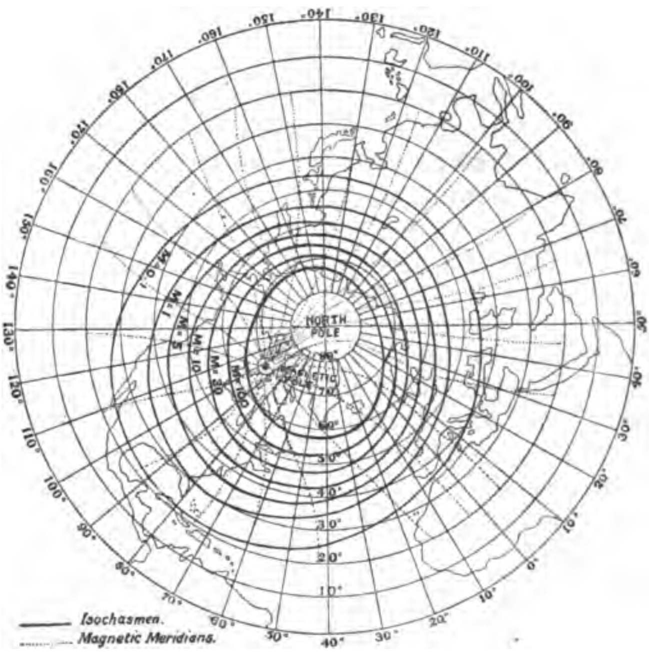


Fig. 45.—Chart of the Isochasmen Lines, or lines of equal auroral frequency.

single or double ring of auroral light, which he calls the "Aurora Glory." He says, concerning this phenomenon:

Nordenskjöld and the aurora glory.

"Our globe, even during a minimum aurora year, is adorned with an almost constant crown of light, single, double, or multiple, whose inner edge was

usually, during the winter of 1878-79, at a height of about 0.03 of the radius of the earth (120 miles) above its surface, whose surface was somewhat under the earth's surface, having its centre a little north of the magnetic pole, and which, with a diameter of about 0.32 radius of the earth (about 1,280 miles), extends in a plane perpendicular to the earth's radius which passes through the centre of this luminous ring."

Fig. 46, taken from Nordenskjöld's "Arctic Voyages," shows the Aurora Glory as a double luminous ring. The inner ring, called the common arc, is more regular than the outer ring, and is always present. The outer ring is sometimes absent.

Inner ring and common arc of Aurora Glory.

Fig. 46.—Chart showing the position of the Double Luminous Crown or the Aurora Glory, after Nordenskjöld. Note, by comparison with Fig. 71, that the centre of the Aurora Glory is nearly coincident with the magnetic pole.

As to the cause of the aurora, there appears to be no doubt that it is due to electric discharges passing through the rarer layers of the atmosphere. It is certain that effects almost precisely similar to the aurora can be produced by the passage of discharges of high electro-motive force through vacuum tubes.

Disturbance of telegraph lines by atmospheric electricity.

Moreover, during the prevalence of the aurora, an excess of free electricity is almost invariably observed to be in the air. During these times telegraphic lines will collect sufficient electricity from the air to operate the instruments, without the aid of the voltaic batteries that are generally employed. Not infrequently, the quantity of electricity so collected is sufficient to prevent the proper operation of the line. So well are these facts known to telegraph men that when they observe such disturbances to occur during the day, they generally look for auroral displays the same night, and are seldom disappointed in their expectations. Sometimes the quantity of free electricity thus collected from the air is sufficiently great to violently ring the call bells employed on the lines.

Connection between telegraphic disturbances and auroral displays.

Electric storm of November 17, 1882.

In this connection it will be interesting to note the following account taken from the United States Signal Service Reports of an electric storm which occurred in the United States, November 17, 1882. This storm began shortly before daylight, and manifested itself by interfering with the telegraph lines. For at least three hours the Western Union Telegraph Company had not a single wire over its entire system that could be properly worked. The trouble decreased later in the day, and afterward, at night, a brilliant aurora prevailed over the eastern half of North America, over all the Atlantic Ocean, and most of Northwestern Europe, where all telegraph service was interrupted. Neither the cables to Europe nor the land lines in America could be operated. The call annunciators in the telephone offices dropped by reason of the action of atmospheric currents, and at Albany and Chicago the switchboards were destroyed by fires of electric origin, due to the passage of excessive electrical currents taken from the

Interference in trans-atlantic cables and overland telegraph lines.

air. At St. Paul, Minnesota, the currents taken from the air were sufficiently strong to operate an incandescent electric lamp. Telegraphic messages were sent from Bangor, Maine, to North Sydney, Cape Breton Island, a distance of 710 miles, by currents taken from the earth. This line was ordinarily operated by means of currents taken from 100 cells of the common telegraphic battery.

Telegraphic messages sent by earth currents.

De la Rive regards the connection between atmospheric electricity and the aurora as unquestioned. He thus remarks concerning auroral phenomena:

"We have seen that the atmosphere is constantly charged with positive electricity—electricity furnished by the vapors that rise from the sea, essentially in tropical regions, and that, on the other hand, the earth is negatively electrized; the recomposition or neutralization of the two contrary electricities of the atmosphere and of the terrestrial globe is brought about by means of the greater or less moisture with which the lower strata of the air are impregnated. But it is especially in the polar regions, where the eternal ices, that reign there constantly, condense the aqueous vapors under the form of haze, that this recomposition must be brought about; the more so as the positive vapors are carried thither and accumulated by the tropical current, which, setting out from the equatorial regions, where it occupies the most elevated regions of the atmosphere, descends in proportion as it advances toward the higher latitudes, until in the neighborhood of the poles, where it comes into contact with the earth. It is there then that the discharge between the positive electricity of the vapors and the negative electricity of the earth must essentially take place, with accompaniment of light, when it is sufficiently intense; if, as is almost always the case near the poles,

De la Rive on the causes of auroral phenomena.

Why auroral displays occur in high latitudes.

and sometimes in the higher parts of the atmosphere, it meets on its route with extremely small icy particles, which constitute the hazes and the very elevated clouds."

Influence of earth's magnetism on auroral phenomena.

De la Rive then points out the effects that should be produced by the earth's magnetism on the moving parts of the luminous haze referred to in the above quotation, which practically act as a moving electric conductor, and describes a form of apparatus by means of which results similar to aurora may be artificially produced by the combined action of electric discharges and magnetism.

Reaction between the earth's magnetism and the luminous haze, which is a movable electric conductor.

"Now, if we examine what ought to take place in the portion of the luminous haze, which is nearest to the terrestrial globe, and consequently to the polar regions, we shall find that the magnetic pole should exercise over this electrized matter, which is a veritable movable conductor, traversed by a succession of discharges, an action analogous to that which is exercised in the experiment that we have described when engaged with the luminous effects of electricity, by the pole of an electro-magnet over the jets of electric light that are made to converge in extremely rarefied air. We have seen that, as soon as the soft iron cylinder, which serves as an electromagnet, is magnetized, the electric light, instead of coming out indifferently from the divers points of the upper surface, that serve as a pole, as had taken place before the magnetization, comes out only from all the points of the circumference of this surface, so as to form around it as it were a continuous luminous ring. This ring possesses a movement of rotation around the magnetized cylinder, sometimes in one direction, sometimes in another, according to the direction of the discharge and the direction of the magnetization. Finally some more brilliant jets

Cause of Aurora Glory.

seem to come out from this luminous circumference, without being confounded with the rest of the group."

It is interesting to note, as showing the relation between the magnetism of the earth and auroral phenomena, that the occurrence of aurora is nearly always simultaneous with the occurrence of an unusual number of sun spots, and also that magnetic storms, or storms in which the magnetism of the earth undergoes marked changes both in direction and intensity, occur also especially during the time both of sun spots and of unusual auroral activity.

Relation between auroral phenomena, sun spots and magnetic storms.

A spectroscope examination of the light emitted by an aurora shows the presence of a few bright lines, which, although they in general resemble the spectrum of the light produced by electric discharges passing through ordinary air, yet, according to S. P. Thompson, are not referable to any known substance.

Spectroscopic examination of auroral light.

CHAPTER VII

THERMAL, MECHANICAL, AND OTHER EFFECTS OF ELECTRIC DISCHARGES

"First let me talk with this philosopher;
What is the cause of thunder?"
—*King Lear,* Act III, Scene IV.

Thermal effects of electric discharges.

THE passage of disruptive discharges through air is invariably attended by an increase in temperature. This increase in temperature, of course, produces an expansion or increase in volume. In addition to the increase of temperature, a violent mechanical motion is set up by the discharge in the particles of the air. Kinnersley, in 1761, devised a simple form of electric thermometer which depends for its operation on the expansion of the air produced by the increase of temperature.

Kinnersley's electric thermometer.

Kinnersley's electric thermometer is shown in Fig. 47. It consists of two glass tubes of unequal diameter, communicating with each other at their lower ends. The larger tube is closed by a metallic cap, through which extends a metallic rod, terminating at each end with metallic balls. Another metallic ball is supported on a conducting vertical rod, fixed to the lower part of the tube, leaving an air gap between it and the lower end of the ball connected with the upper rod. The smaller tube is open at the top, and enough water is placed in the two vessels to fill them to a level below the top of the lower ball.

Double action of electric discharge.

On the passage of a disruptive discharge through the air between the two balls within the inclosed tube, as by the discharge of a Leyden jar, an expansion of the contained air, caused by the increase of temperature, forces the water to rise in the open tube, and, with very strong discharges, even to be violently expelled from the top. The rise of the water is also due to the violent motion imparted to the water in the inclosed glass tube; but that it is also due to the

FIG. 47.—Kinnersley's Electric Thermometer. The distance between the electrodes in the inclosed tube can be readily changed by sliding the upper rod toward or from the lower fixed ball. Note that a disruptive discharge has occurred, since the liquid stands at a higher level in the small tube than it does in the large tube.

increased temperature of the contained air is shown by the fact that the water remains at a higher level in the open tube until the air in the inclosed tube regains its former temperature. In order to increase the temperature of the air in the inclosed tube on the passage of the discharge, and thus render the in-

Proof that the rise of liquid is due to development of heat.

strument more sensitive, a thin metallic wire, or a narrow strip of gilt paper, is sometimes placed between the two metallic balls.

Quantity of produced heat.

The quantity of heat produced by the above electric discharges is proportional to the quantity of electricity that passes, and to the difference of potential through which it falls. But the laws governing the production of heat by electricity will be better understood when we have studied more fully current electricity as produced by voltaic batteries.

Reiss's and Mascart's modifications of Kinnersley's thermometer.

Riess, in 1837, increased the sensitiveness of Kinnersley's thermometer by placing a spiral of fine platinum wire between the two balls, as well as by placing the smaller of the tubes in a horizontal position. Mascart, in 1873, still further improved the instrument by making it self-registering or recording. This he did by the use of a diaphragm of sheet rubber, moved by the expansion of the air. The movements of this diaphragm acted on a pivoted lever, which, resting on a sheet of smoked paper, left on it a tracing or record of its movements.

Electric mortar.

A more striking manner in which to show the increase of temperature by the passage of a disruptive discharge is by means of the electric mortar. This simple apparatus consists of an inclosed space within the body of a mortar, provided with two blunt terminals, connected with metallic rods extending through the sides of the mortar. The passage of the discharge through the air between the inclosed terminals causes its sudden expansion, and this expels the ball from the mortar. In order to produce better results, a few drops of ether, placed in the mortar before the passage of the discharge, produces an explosive mixture of ether vapor and air. This mix-

ture, ignited by the passage of the spark, violently projects the ball.

The ability of the spark to ignite ether vapor may be shown in the manner indicated in Fig. 48. Here the ether is placed in a metallic cup, provided with a ball in its lower end. On the discharge of a Leyden jar, as shown, the spark passes between the positive and negative terminals, and ignites the ether vapor. A gas jet of ordinary illuminating gas may be ignited in the same way. This method is employed in the electric igniting of gas jets. The heat

Ignition of combustible substances by electric sparks.

FIG. 48.—Ether set on fire by a Disruptive Discharge from a Leyden Jar.

of the electric spark is also capable of igniting gunpowder, but here, in order to avoid the scattering of the powder, a moistened string takes the place of one of the conducting wires, and thus lessens the violence of the discharge.

The discharges from large Leyden-jar batteries, when passed through fine metallic wires, are capable of deflagration; *i.e.* fusing and volatilizing them. Here the intensity of the heat so produced not only fuses the wire, but raises its temperature so high that the molten metal is actually boiled and is caused explosively to pass off into the air as metallic vapor.

Deflagration of metals.

This action is spoken of as deflagration. The increase of temperature for such an action is necessarily very marked, since the temperature of the fusion of such metals as gold, silver and copper is quite high, being 2016° F. for gold, 1873° F. for silver, and 1996° F. for copper.

Melting-points of gold, silver and copper.

The ability of a Leyden-jar discharge thus to fuse metals is sometimes utilized in the very beautiful experiment shown in Fig. 49. A portrait, in the pres-

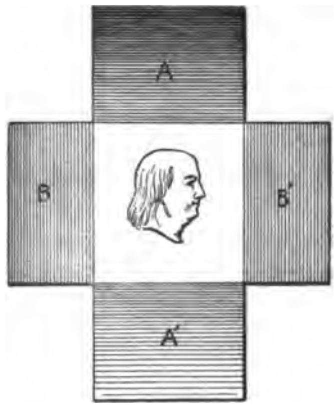


FIG. 49.—Silhouette of Franklin impressed on a piece of white silk by the deflagration of a gold leaf by an electric discharge.

ent instance of Franklin, is cut from a thick sheet of paper by suitable outlining and perforations, and placed on a piece of white silk. A sheet of gold leaf is then placed on the paper and the strips of tin-foil, A, A′, placed at the top and bottom of the design, are folded down over it, and the whole placed in a press, which is tightly screwed together. If, now, the discharge from a Leyden-jar battery is passed through the package, by connecting the projecting sheets of tin-foil, B, B′, with the terminals of the

Electric silhouettes.

battery, the gold leaf is volatilized by the heat of the discharge, and a blackish stain of gold is left on the white silk in the form of the design traced on the paper.

The heating power of the disruptive electric discharge is shown by the fact already referred to, that during the discharge small particles are torn from the surfaces of the metallic balls attached to the conductors of the electric machine, or from the metallic surfaces between which the discharge passes. It is the volatilization of these metallic particles that produces the characteristic colors of the disruptive discharge, their glowing vapors emitting different colored lights.

Color of spark often due to glowing metallic vapors.

The amount of metal volatilized increases with the intensity of the discharge, and is, therefore, greater in air at ordinary pressures; but, even in a partial vacuum, where the pressure is considerably reduced, this volatilization is present, and may readily be detected by the spectroscope.

If a cool surface, such as a glass plate, is exposed to the metallic vapors produced by electric discharges in partial vacua, the vapors are condensed, and the metal deposited on the glass in the shape of very thin metallic films. Wright employed this method to obtain metallic coatings. He produced, in this way, metallic films, the particles of which cohered, or clung to one another, as strongly as though they had been produced by beating or rolling. These films, although continuous, that is, free from perforations, were so thin as to be transparent to light. Wright found that the metals differed greatly from one another in their ability to be so transferred and deposited on cool surfaces. Bismuth, gold, and

Wright's electric method of obtaining transparent metallic films.

platinum were readily obtained in the shape of thin films, while aluminium and magnesium could only be obtained with great difficulty. It is for this reason that in vacuum tubes the terminals inside the tubes are generally formed of aluminium, while outside the tube platinum is employed. The preference is given to the employment of platinum in all cases where the wires require to be fused or sealed into the substance of the glass tube, from the fact that platinum expands and contracts at about the same rate as glass does. Consequently, differences in its temperature, caused by the passage of discharges through

Why vacuum-tube terminals are made of aluminium.

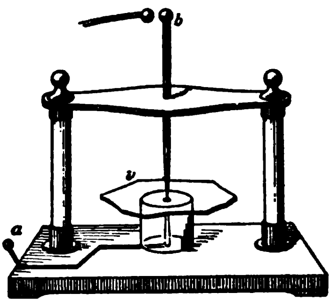


FIG. 50.—Mechanical Effect of a Disruptive Discharge. A plate of glass pierced by the discharge from a Leyden-jar battery.

a platinum wire, do not result in the breaking of the glass, as might be the case were metals employed whose rate of expansion differed greatly from that of the glass.

Use of platinum for leading-in wires.

The mechanical effects produced by a disruptive discharge consist in the tearing, breaking, shattering, or piercing of the non-conducting substances through which the discharge passes. The passage of a disruptive discharge through ordinary air is, in fact, accomplished by a smashing or rupturing of the air. This breaking, however, is not so ap-

parent as in the case of glass, or other dielectric, since the air tends almost immediately to flow together, and thus mend the broken parts. The resistance of the dielectric to breaking or piercing by the electric discharge is called its dielectric resistance. For example, the dielectric resistance of glass is much greater than that of air. Glass, however, may be broken or pierced by the disruptive discharge. When such discharges are sufficiently powerful, even thick slabs of glass may be pierced. The manner in which this experiment may be tried by aid of the discharge of a Leyden-jar battery is shown in Fig. 50. Here the charge of a Leyden-jar battery is passed through a sheet of glass, *v*, placed between metallic points, shown in the figure. One coating of the battery is connected with *b*, and the other with *a*. In order to concentrate the electric discharge at the point to be pierced, and thus prevent it from spreading over the surface of the glass, the metallic points, placed immediately above and below the point that it is desired to pierce, are previously dipped in some insulating oil. On the passage of the discharge, a small aperture is made in the glass, which is found, on examination, to be filled with finely powdered glass.

Dielectric resistance.

Piercing of glass by electric discharges.

In case of the passage of the discharge through such partially conducting substances as wood and paper, in which a small quantity of water is invariably present, a rapid formation of vapor taking place within the mass of the material, by the heat of the discharge, causes an explosion that violently tears or rends the substance. In the case of powerful discharges like lightning flashes, this rending action is sufficiently great to hurl fragments of the non-conducting substance through the air for considerable distances. Such effects have often been noticed

Cause of explosions of bad conductors by electric discharges.

when lightning flashes strike trees or other semi-conducting substances. As we shall see later on in the book, the explosive action of lightning discharges may be due to another cause.

Explosions due to formation of vapors.

That the action above described is sometimes due to the explosive formation of vapors in the substance of the partial conductor is shown by sending the discharge through a piece of ordinary cardboard, or through 50 or 100 leaves of paper in a book. This may be done by arranging the cardboard or the book in a manner similar to that of the glass plate described in connection with Fig. 50. On the passage of the discharge, a raised or burred edge is found on both sides of the sheet of paper, or on the sides of those leaves of the book which are nearer respectively to the positive and negative terminals of the battery. Here, evidently, the heat developed by the discharge has suddenly liberated a mass of vapor which has explosively forced its way through the opening in both directions, that is, from some point near the middle toward both the positive and negative terminals.

A curious fact will be noticed in this connection; viz., that if the metallic points carrying the discharge through the card, or the leaves of the book, are not placed directly opposite each other, the aperture is always nearer the negative terminal. This is, probably, due to the fact noticed by Faraday, that negative electricity escapes more readily into the atmosphere than does positive; for, if the experiment be tried in a vacuum, then no such displacement of the aperture is observed.

The mechanical effects, produced by the passage of the discharge through water, may be illustrated

by causing the discharge of a Leyden-jar battery to pass through a small quantity of water placed in a tightly corked test-tube or other tube of thin glass. On the passage of the spark, an agitation of the water, due to its sudden expansion, takes place, sufficient to break the tube into many pieces. The repulsion of air particles from charged pointed conductors occurring in convective discharges is another instance of mechanical effects produced by these discharges.

Chemical effects of electric discharges.

The chemical effects of the electric discharge will be best studied in detail under the head of current electricity. A few of the more important of the chemical effects produced by disruptive discharges will, however, be mentioned here. It must not be supposed that this is because electricity produced by different electric sources produces different chemical effects; for, as Faraday has demonstrated, no matter from what source an electric current or discharge is produced, its chemical effects are one and the same.

Priestley.

Discharges passed through water produce an acid substance.

Priestley has shown that the passage of a number of electric discharges through water, colored with litmus, a blue vegetable material, results in the production of a substance that turns the color of the blue litmus to red, thus indicating the formation of an acid substance. The addition of a few drops of acid to blue litmus water instantly turns it red; on the contrary, the presence of a basic or alkaline substance, such as a drop of ammonia or washing soda, will instantly restore the blue color to reddened litmus water. The acid substance formed by the passage of the disruptive discharge through water in the above experiment is nitric acid. Ordinary water always contains a quantity of oxygen and nitrogen, which it absorbs from the air that comes in contact

Origin of nitric acid

with it. The discharge, by its chemical action, has caused this nitrogen and oxygen to combine and form nitric acid, and this substance instantly reddens the blue litmus.

Production of ozone by electric discharges.

One can not fail to notice the peculiar odor that exists in the neighborhood of a powerful electric machine after it has been in operation for some time. This odor is due to the formation of a peculiar modification of oxygen called ozone. Ozone possesses very energetic powers of oxidizing substances, that is, of causing them to enter into combination with oxygen. It is also capable of acting as a powerful

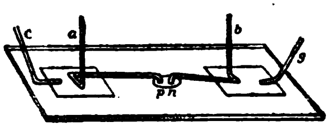


FIG. 51.—Faraday's apparatus for producing chemical decompositions by means of disruptive discharges

germicide or a material capable of killing the organic germs that we now know are the causes of many contagious diseases.

Faraday's apparatus for studying the chemical effects of electric discharges.

Fig. 51 shows an apparatus devised by Faraday for readily decomposing chemical substances by the passage of disruptive electric discharges. A glass plate has two pieces of tin-foil placed, as shown, near two of its opposite edges. Two bent platinum wires, *a* and *b*, are so placed on the tin-foil that their extremities, *p* and *n*, touch a small piece of blotting paper moistened with the substance which is to be decomposed by the electric discharge. The wire *c*, connected with the positive conductor of an electric machine, is in connection with *a* by means of the tin-foil; a long wire, *g*, connected with the negative

conductor, or with a discharging wire, is similarly in connection with *n*. By these means *p* and *n* become the positive and negative terminals, or the decomposing poles. If now, under these circumstances, a series of discharges is sent through the paper, decomposition occurs. If the substance placed on the paper, in this case a piece of paper moistened with litmus solution, be sulphate of soda, then the decomposition of the salt is shown by the reddening of the paper at *p*, the positive terminal, thus indicating the liberation of an acid material at this point.

The direct discharge passing through various gaseous substances, such as ammonia gas, causes their

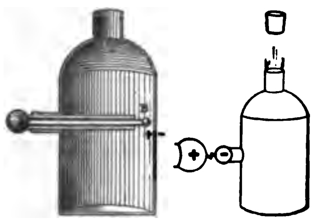


Fig. 52.—Electric Pistol.

chemical decomposition. Such discharges also possess the power of causing substances to enter into chemical combination. Thus, a discharge passed through a mixture of ordinary illuminating gas and air will produce an explosive combination of some of the constituents of the mixture. This may be shown experimentally by placing a mixture of illuminating gas and from six to eight times its volume of air in a tightly corked tin vessel, as shown in Fig. 52. In order to ensure the passage of the spark through the mixed gases within the vessel, an insulated conductor passes through one wall of the pistol and termi-

Gaseous combinations caused by electric discharges.

nates with a smooth, metallic ball B near the opposite wall, as shown on the left hand of the figure.

Magnetic effects of electric discharges.

Disruptive discharges, like all electric discharges, are invariably attended by magnetic effects. This will be better understood after we have studied the phenomena of magnetism. A few cases, however, of the production of magnetism by disruptive discharges may be cited here. If the discharge of a Leyden-jar battery be caused to pass through an unmagnetized steel needle, it will produce in it a permanent magnetization. In a similar manner, powerful Leyden-jar discharges will reverse the magnetism of compass needles, either when they pass through the needles, or in their immediate neighborhood. It has often been noticed that lightning discharges have, in this manner, reversed the polarity of a ship's compasses.

Reversal of magnetism of ship's compasses by lightning strokes.

The physiological effects of disruptive discharges have attracted the attention of scientific men ever since Von Kleist, Cuneus, and Muschenbroeck received, so unexpectedly, the discharge from their little Leyden jars. The strange and mysterious nature of this new agent, the violent, involuntary muscular contractions which it caused, possessed a fascination for these early experimenters, and many trials were made of this peculiar power of the discharge; for example, Nollet sent the discharge through a long chain, formed by more than 600 people grasping each other by the hands. He found that those in the middle of the chain were as violently affected by the discharge as those near its two extremities, and therefore closer to the metallic coatings of the jar.

Physiological shock caused by Leyden-jar discharges.

Von Marum killed eels by the passage through

their bodies of a moderately strong charge. All animals can be killed by the passage of sufficiently powerful discharges. In case of very powerful discharges death appears to be so instantaneous that the animal still retains the position it had just before the discharge. This fact is frequently noticed in cases of people struck dead by lightning flashes.

Death caused by electric discharges.

Electric discharges or currents are capable of producing healing or therapeutic effects on the human body. Electricity is unquestionably a powerful remedial agent, but, like all powerful agencies, should be intelligently applied to the human body, otherwise it may cause serious damage to the health. The manner of its application as a therapeutic agent, the laws according to which it operates, and other details of such applications, will be discussed under the head of electro-therapeutics.

Electro-therapeutic effects of electric discharges.

The effects of electric discharges are not, however, limited to the bodies of animals. They also affect plant life. Electric discharges produce, it is claiméd, marked influence on the growth of vegetation. As early as 1703, Bertholon wrote a book that was devoted entirely to the influence of electricity on vegetable life. Since his time efforts have been made to accelerate vegetable growth by drawing atmospheric electricity from the air into the ground. Very considerable attention has been paid to these efforts, so that electro-culture may be regarded as a new art. Much remains, however, to be learned concerning this art.

Influence of electric discharges on vegetable life.

Electro-culture.

CHAPTER VIII

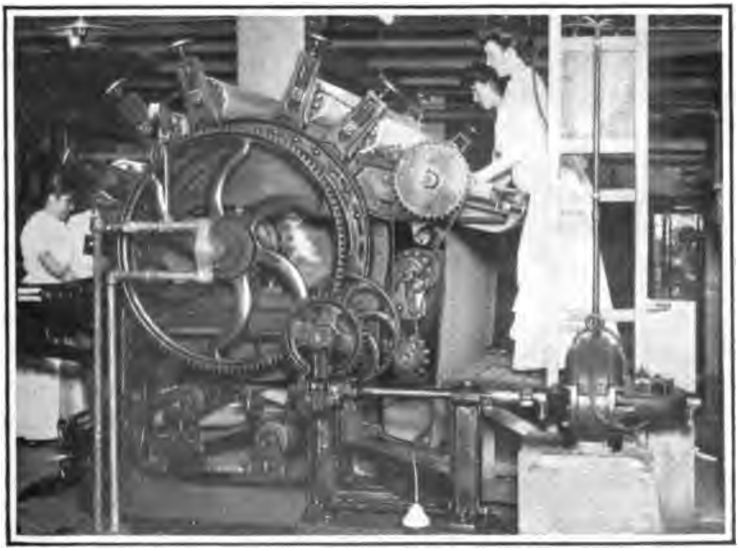
FRANKLIN AND THE ELECTRIC KITE—ATMOSPHERIC ELECTRICITY

"Let the experiment be made."
—BENJAMIN FRANKLIN: *Letter*, March 18, 1755

Early suspicions of lightning and thunder being electrical phenomena.

IT was not until shortly after the middle of the eighteenth century that the world was able to obtain indisputable proof that thunder and lightning are effects produced by powerful electric discharges, taking place either between neighboring clouds, or between a cloud and some tall object on the earth. It is true that, long before this time, philosophers had suspected such a relationship. Even before their electrical machines were capable of producing fairly powerful discharges, the similarity in the luminous appearances, caused by such discharges, and the crackling noises attending them, led to the beginnings of a belief that these phenomena were similar to those produced by lightning and thunder. As electrical machines were improved, and more and more powerful discharges were obtained from them, this belief grew stronger and stronger, until at last, several years before Franklin immortalized himself by robbing Jove of his thunder bolts, the belief had reached such a stage that, at least in Franklin's mind, it practically amounted to a certainty. Before describing in detail Franklin's experiment, we will briefly note some of the more important of these early suggestions and pre-

Suspicions growing into beliefs.



ELECTRICITY IN THE LAUNDRY

The upper picture shows the use of electrically heated irons in a hotel laundry. The lower picture is of a mangle, rotated by an electric motor, in the laundry of an apartment house

dictions, as to the identity of these two classes of phenomena.

In 1705, Hawkesbee, by means of an interesting series of experiments, discovered that luminous effects are produced when mercury is allowed to fall from the top to the bottom of a glass tube, in which a partial vacuum is maintained. He also produced similar luminous effects by causing air to pass rapidly through mercury contained in a glass vessel, in which also a partial vacuum was maintained. In one of these experiments, by causing the mercury to fall in a shower against the rounded top of a second glass vessel, he obtained luminous effects which, he said, "produced flashes resembling lightning." At a later date, we find Hawkesbee noting the luminous effects produced by the friction of a woollen cloth against a glass tube. In speaking of these effects, he said that he "observed light to break from the agitated glass in as strange a form as lightning." We know now that the luminous effects produced in the case of the mercury experiments were due to electric discharges, produced by the friction of air against the mercury and the glass, passing through the partial vacuum of the vessel. But Hawkesbee does not appear to have known that it was electric phenomena he was dealing with, and, although in the case of the piece of rubbed glass he must have known that electrical effects were produced, yet in neither of these classes of phenomena does he appear to have ascribed the flashes of light, as we now would, to the passage of electric discharges.

Hawkesbee's "Experiments on Luminous Effects in Mercury Tubes."

Hawkesbee's ignorance of electric origin of mercury tube effects.

In 1705, Gray called attention, in the "Philosophical Transactions," to the resemblances that ex-

Gray.

ist between the effects of electric discharges and lightning and thunder.

Wall.

In 1708, Wall thus called attention, in the "Philosophical Transactions," to the resemblance between the crackling and flash produced by rubbed amber and thunder and lightning: "This light and crackling seem in some degree to represent thunder and lightning."

Abbe Nollet on electric phenomena and lightning and thunder.

Abbe Nollet, in the fourth volume of his "Lessons in Physics," published near the close of 1748, expresses himself in the following language:

"If any one should undertake to prove, as a clear consequence of the phenomenon, that thunder is in the hands of nature what Electricity is in ours—that those wonders which we dispose at our pleasure are only imitations on a small scale of those grand effects which terrify us, and that both depend on the same mechanical agents, if it were made manifest that a cloud prepared by the effects of the wind, by heat, by a mixture of exhalations, etc., is in relation to a terrestrial object what an electrified body is in relation to a body near it not electrified, I confess that this idea, well supported, would please me much; and to support it how numerous and specious are the reasons which present themselves to a mind conversant with Electricity. The universality of the electric matter, the readiness of its actions, its instrumentality and its activity in giving fire to other bodies, its property of striking bodies externally and internally, even to their smallest parts (the remarkable example we have of this effect even in the Leyden-jar experiment, the idea which we might truly adopt in supposing a greater degree of electric power), all these points of analogy which I have been for some time meditating, begin to make me believe that

Nollet on the resemblances between electrical discharges and lightning.

one might, by taking Electricity for the model, form to one's self in regard to thunder and lightning more perfect and more probable ideas than hitherto proposed."

After the discovery of the Leyden jar, and the phenomena attending the discharge of an electrified body by points, the connection between some luminous phenomena of the atmosphere, other than lightning flashes, became probable to scientific men. Among such phenomena may be mentioned the faint tongues of fire, already referred to as being often seen on the masts of ships, steeples, or other tall bodies. These appearances are due to electric discharges known as brush discharges. As we shall afterward see, brush discharges are the same as convective discharges. Such discharges, as already pointed out, are due to the electrically charged particles of air that are driven by repulsion from any sharp points connected with electrically charged surfaces. In the forty-eighth volume of the "Philosophical Transactions," Watson calls attention to the fact that certain appearances referred to by Pliny, in his "Natural History," as occurring on the yards of the Roman ships, or on the ends of the soldiers' spears in the Roman camp, were evidently due to the existence of electricity in the atmosphere.

Watson on other luminous phenomena of atmosphere.

Pliny.

The preceding references will show that both suspicions, and almost beliefs, existed in the minds of scientific men, as to the identity of electric discharges and lightning flashes, before the time of Franklin. Still it remained for Franklin, by actual demonstration, to place the identity of these two classes of phenomena beyond the possibility of doubt.

Before proceeding to describe in detail Franklin's

Strength of Franklin's belief as to identity of lightning flashes and electric discharges.

famous experiment with the kite, it will be interesting to show how strong Franklin's belief was as to the identity of lightning and thunder and the discharge and report of an electrified conductor.

Franklin's article on thunder-gusts.

There exists among Franklin's writings a scientific paper in the form of a letter to a Mr. Collinson. This paper is entitled "Observations and Suppositions toward forming a new Hypothesis, for explaining the several Phenomena of Thunder Gusts." Unfortunately, this paper bears no date, but, since Franklin refers to it in a subsequent letter to Mr. Collinson, dated 1753, as his former paper written in 1747, and enlarged and sent to England in 1749, we are justified in placing its date at some time during, or prior to, 1749. This paper, or letter, is to be found in almost any complete work on Franklin's life, and will well repay a careful perusal. Considering its probable early date, it contains remarkably precise statements concerning the subject of which it treats.

Extracts from Franklin's note-book, November 7, 1749.

But apart from the Collinson paper, Franklin himself fixes a date, viz. November 7, 1749, at which he recorded in a note-book the reasons he had for being convinced of the identity between electric discharges and lightning flashes. This we take from one of Franklin's books entitled "Experiments and Observations on Electricity, made at Philadelphia, in America." On page 322 of this book, in a letter to Dr. L., of Charleston, South Carolina, dated March 18, 1755, he says:

How Franklin came to try kite experiment.

"Your question, how I came first to think of proposing the experiment of drawing down the lightning, in order to ascertain its sameness with the electric fluid, I can not answer better than by giving you an extract from the minutes I used to keep of

the experiments I made, with memorandums of such as I purposed to make, the reasons for making them, and the observations that arose upon them, from which minutes my letters were afterward drawn. By this extract you will see that it might have occurred to any electrician.

" 'November 7, 1749. Electrical fluid agrees with lightning in these particulars: 1. Giving light. 2. Color of the light. 3. Crooked direction. 4. Swift motion. 5. Being conducted by metals. 6. Crack or Noise in exploding. 7. Subsisting in water or ice. 8. Rending bodies it passes through. 9. Destroying animals. 10. Melting metals. 11. Firing inflammable substances. 12. Sulphureous smell. The electric fluid is attracted by points. We do not know whether this property is in lightning. But since they agree in all the particulars wherein we can already compare them, is it not probable they agree likewise in this? Let the experiment be made.' "

Franklin on resemblances between electricity and lightning.

Franklin conceived two plans for making the experiment above referred to. One was to place a pointed insulated conductor on the outside of a church spire, permitting it to project above the top of the spire. By this means he hoped, during the progress of a thunderstorm, to be able to draw electrical discharges from its lower end. Unfortunately for Franklin, there were no church spires in the city of Philadelphia at that time, by means of which he could readily try his experiment, therefore, after waiting for such to be erected, he conceived the second plan; viz., of actually making his experiment in the very heart of the clouds by means of a kite.

Franklin's plans for drawing electricity from the clouds.

This never-to-be-forgotten kite was a common, everyday boy's kite, consisting of two light wooden

Franklin's kite.

arms, covered, however, in this case, with silk instead of paper, so as to permit it to be employed in wet weather. The kite was raised by means of an ordinary hempen string, insulated at the end by a silk ribbon. The hempen string had a key connected to its lower end, near the ribbon. The key was provided to serve the purposes of a conductor. At the top of the upright wooden arm of the kite he placed an iron point, for the purpose of drawing the electric charge from the cloud, if, as he firmly believed, it was present during a thunderstorm.

Thus provided, Franklin, accompanied by his son, in order that the unusual sight of a grave philosopher kite-flying might not excite too marked public attention, proceeded to a Philadelphia common, situated, as nearly as we can learn, somewhere near Spring Garden Street, between 18th and 20th. He succeeded in raising the kite during the approach of a thunderstorm, and, after repeated trials, at last had the great satisfaction of being able to draw from the key sparks possessing all the properties of those produced by the electrical machine with which he was so familiar. In this way was realized one of the grandest discoveries in the domain of electric science, and the actual identity between the lightning flash and electric discharges was thus demonstrated beyond any possible doubt.

The immortalization of Franklin.

We annex the following description of this original experiment, prepared shortly after Franklin's experiment.

"Furnished with this apparatus, on the appproach of a storm, he went out upon the commons near Philadelphia, accompanied by his son, to whom alone he communicated his intentions, well knowing the ridicule which would have attended the report of

Contemporary account of Franklin's experiment.

such an attempt should it prove to be unsuccessful. Having raised the kite, he placed himself under a shed, that the ribbon by which it was held might be kept dry, as it would become a conductor of electricity when wetted by rain, and so fail to afford that protection for which it was provided. A cloud, apparently charged with thunder, soon passed directly over the kite. He observed the hempen cord; but no bristling of its fibres was apparent, such as was wont to take place when it was electrified. He presented his knuckle to the key, but not the smallest spark was perceptible. The agony of his expectation and suspense can be adequately felt by those only who have entered into the spirit of such experimental researches. After the lapse of some time he saw that the fibres of the cord near the key bristled, and stood on end. He presented his knuckle to the key and received a strong, bright spark. It was lightning. The discovery was complete, and Franklin felt that he was immortal."

The critical moment.

Sampling a lightning flash.

It will be interesting to read the following account which Franklin himself gives of the construction of his now famous kite, and of its action during the presence of a thundercloud. This description is taken from a letter dated October 19, 1752. Note particularly the extremely modest manner in which Franklin refers to this great experiment. We find here not the laudatory remarks of an investigator too egotistically alive both to his own greatness, and to the value of his discovery, but the clear explanations of a man of science, as to the precise method in which he proceeded to obtain the results.

Franklin's modest description of his kite.

"As frequent mention is made in public papers from Europe of the success of the Philadelphia experiment for drawing the electric fire from clouds by means of pointed rods of iron erected on high

buildings, etc., it may be agreeable to the curious to be informed that the same experiment has succeeded in Philadelphia, though made in a different and more easy manner, which is as follows:

The kite, as Franklin made it.

"Make a small cross of two light strips of cedar, the arms so long as to reach to the four corners of a large, thin silk handkerchief when extended; tie the corners of the handkerchief to the extremities of the cross, so you have the body of a kite; which being properly accommodated with a tail, loop, and string, will rise in the air, like those made of paper; but this being of silk, is fitter to bear the wet and wind of a thunder-gust without tearing. To the top of the upright stick of the cross is to be fixed a very sharp pointed wire, rising a foot or more above the wood. To the end of the twine, next the hand, is to be tied a silk ribbon, and where the silk and twine join a key may be fastened. This kite is to be raised when a thunder-gust appears to be coming on, and the person who holds the string must stand within a door or window, or under some cover, so that the silk ribbon may not be wet; and care must be taken that the twine does not touch the frame of the door or window.

How the kite operated.

As soon as any of the thunder clouds come over the kite, the pointed wire will draw the electric fire from them, and the kite, with all the twine, will be electrified, and the loose filaments of the twine will stand out in every way, and be attracted by an approaching finger. And when the rain has wet the kite and twine so that it can conduct the electric fire freely, you will find it stream out plentifully from the key on the approach of your knuckle.

Sample of lightning tested and shown to be the same as ordinary electricity.

At this key the phial may be charged; and from electric fire thus obtained, spirits may be kindled, and all the other electric experiments be performed, which are usually done by the help of a rubbed glass globe or tube, and thereby the sameness

of the electric matter with that of lightning completely demonstrated."

Franklin's great discovery naturally created an intense excitement in scientific circles in all parts of the world. Other investigators did not hesitate in repeating them. We will only give an account of two of the most interesting of these.

Electric kite of Romas.

On the 7th of June, 1753, a French philosopher, Romas, repeated Franklin's experiment. He employed a kite similar to that constructed by Franklin, only, in order to render the hempen cord more conducting, he employed a wire interwoven between the strands of the cord. This kite was 7½ feet high, and 3 feet wide, so that it had some 18 square feet of surface.

Results obtained by means of Romas's kite.

The following results were obtained by Romas by the aid of this kite. When he succeeded in raising it some 550 feet above the ground, he drew sparks from a tin tube, connected to the string of the kite and employed as a conductor, three inches long and a quarter of an inch thick, the snapping of which, he says, could be heard at a distance of about 200 paces.

The cobwebs' warning.

Romas's precaution.

On one occasion, while making these experiments, Romas felt a sensation as though cobwebs were being drawn over his face, although he was then at a distance of some three feet from the kite. Knowing what this meant, he called aloud to the company with him to retire from the immediate neighborhood of the string. At this time he could not perceive any lightning in the clouds that were immediately over the kite, but, on examining the tin conductor, he noticed that three straws, which he had attached

Romas's experiment with his electric kite.

to the tube for the purpose of serving as electroscopes, were standing erect, thus manifesting the presence of an extremely strong charge on the conductor. This continued for about a quarter of an hour, when the rain beginning to fall, he again perceived the sensation of cobwebs on his face, and heard a rustling noise like that of a small forge bellows. He now withdrew still further from the conductor, and almost immediately afterward saw three brilliant flashes of light near one of the straws, accompanied by three loud explosions, the noise of which greatly resembled that of thunder.

Ozone produced by the electric discharge.

The flashes above referred to were accompanied by an odor which these early observers declared to be the smell of sulphur, but which we now know to be due to the presence of ozone, a modification of the oxygen of the air, caused by the presence of electric discharges. Subsequent examination of the ground below the tin tube or conductor showed the presence of a hole an inch deep and half an inch wide, probably made by the loud flash preceding the explosion.

Death of Richman.

The other investigator in this dangerous domain of experimental science was Professor Richman, who was struck dead on the 6th of August, 1753, by a lightning flash which he drew down from the sky into his laboratory.

Richman's collecting apparatus.

Richman had erected an insulated vertical iron rod on the roof of his laboratory. This rod communicated by a metallic chain, also insulated, with a metal rod fixed to the ceiling of the laboratory. The rod projected downward some little distance from the ceiling, and was terminated by a metallic ball. He had arranged, in connection with this ball, a form of

electrometer of his own construction, consisting of a thread fastened to its lower extremity. The thread hung down by the side of the rod when it was uncharged, but when charged or electrified, was repelled in a manner similar to the pith ball electroscope already described.

At the approach of a thunderstorm, while observing the effects of the electricity of the clouds on the vertical thread of the electrometer, he leaned his head toward it, and while doing so, a gentleman, who was in the laboratory at this time, observed a globe of blue fire, as large as a man's fist, to jump from the rod of the electrometer toward Richman's head, which was at this moment about one foot distant from the rod. This flash instantly killed Richman, and so stunned the gentleman with him, that the latter could afterward give no account of the particular manner in which he had been affected by the stroke. He could only say that, at the moment the professor was killed, there arose, he thought, a sort of steam or vapor which benumbed him, and made him sink upon the ground, and that he could not remember even that he heard the clap of thunder, which was very loud. **Cause of Richman's death.**

Like all lightning strokes, the one which killed Richman did considerable damage to surrounding objects. Half of the glass vessel employed to insulate the rod of the electrometer was broken and thrown in all directions about the room. The casing of the door of the laboratory was split half through, and the door torn off and thrown into the room. **Mechanical effects of discharge.**

Richman was apparently killed instantly by the effect of the lightning stroke. A red spot was **Markings left on body.**

formed on his forehead, the shoe belonging to his left foot was burst, and, on uncovering the foot at that place, a blue mark was found, evidently showing that the discharge had entered at the head, and made its way out at one of the feet.

Dalibard's experiments.

While Franklin was waiting in Philadelphia for the erection of a church steeple, on which he might place his conductor, he wrote to a Frenchman named Dalibard, suggesting the trial of an insulated and pointed metallic rod, extending upward into the atmosphere. At this suggestion, Dalibard erected an iron rod, forty feet high, and succeeded, on the 10th of May, 1752, in drawing electric sparks from its lower extremity. He thus anticipated Franklin by a few weeks, Franklin's successful experiment being made in June, of the same year. Dalibard's experiment, however, was made at the suggestion of Franklin. To Franklin, therefore, and not to Dalibard, is properly given the credit for this grand discovery.

Atmospheric electricity present both in clear and cloudy weather.

It was noticed by the early investigators in this field of research, that electric sparks could be drawn from the lower ends of the pointed conductors erected so as to extend upward into the air above the tops of tall buildings or trees, even when no lightning flashes were visible, and, indeed, even when there were no clouds in the sky. They thus became aware of the fact that there exists some free electricity in the atmosphere at all times. Electricity, therefore, may exist in the atmosphere, both when the weather is cloudy and when it is clear.

Numerous experiments, made on atmospheric electricity, show that the free electricity of the atmosphere is generally positive in character, especially in

clear weather. During rainy weather, it is generally negative, but is apt to change suddenly, and at frequent intervals, from negative to positive, this especially being the case on the approach of fogs, rain, hail, sleet, or snow. As a rule, the higher regions of the atmosphere contain more free electricity than the lower regions. When no electricity can be detected in the lower regions, the mere raising of a pointed conductor into the air, to no greater height than can be reached by an ordinary fishing rod, will frequently show the presence of electricity, when the lower end of the conductor is connected to an electrometer.

Atmospheric electricity generally positive.

Instead of a tall, upright, pointed conductor for obtaining electric charges from the atmosphere, Cross, of England, studied the electrical conditions of the lower regions of the atmosphere by the use of an exploring wire. This consisted of more than a mile of wire, suitably supported on insulators, placed on poles extending nearly 100 feet above the tops of the tallest trees in his park. He connected these wires by means of conductors to his laboratory, and, even during wet, foggy weather, collected sufficient electricity to charge and discharge a Leyden-jar battery of some fifty jars having a total surface of seventy-three square feet, as often as twenty times a minute. Each discharge of this large battery produced a report as loud as the discharge of a cannon.

Exploring conductors or wires of Cross.

Cross gives the following interesting description of the electric effects produced on his exploring wire by the occurrence of a dense November fog:

"Many years since, I was sitting in my electrical room on a dark November day, during a very dense driving fog and rain, which had prevailed for many hours, sweeping over the earth, impelled by a south-

Magnificent atmospheric electric discharges described by Cross.

west wind. The mercury in the barometer was low, and the thermometer indicated a low temperature. I had at this time 1,600 feet of wire insulated, which, crossing two small valleys, brought the electric fluid into my room. There were four insulators, and each of them was streaming with wet, from the effects of the driving fog. From about eight o'clock in the morning until four in the afternoon, not the least appearance of electricity was visible at the atmospheric conductor, even by the most careful appplication of the condenser and multiplier; indeed, so effectually did the exploring wire conduct away the electricity which was communicated to it, that when it was connected by means of a copper wire with the prime conductor of my eighteen-inch cylinder in high action, and a gold leaf electrometer placed in contact with the connecting wire, not the slightest effect was produced upon the gold leaves. Having given up the trial of further experiments upon it, I took a book, and occupied myself with reading, leaving by chance the receiving ball at upward of an inch distance from the ball in the atmospheric conductor. About four o'clock in the afternoon, while I was still reading, I suddenly heard a very strong explosion between the two balls, and shortly after many more took place, until they became one uninterrupted stream of explosions, which died away and recommenced with the opposite electricity in equal violence. The stream of fire was too vivid to look at for any length of time, and the effect was most splendid, and continued without intermission, save that occasioned by the interchange of electricities, for upward of five hours, and then ceased totally. During the whole day, and a great part of the succeeding night, there was no material change in the barometer, thermometer, hygrometer, or wind; nor did the driving fog and rain alter in its violence. The wind

Electric effects obtained during wet weather.

was not high, but blew steadily from the southwest. Had it not been for my exploring wire, I should not have had the least idea of such an electrical accumulation in the atmosphere: the least contact with the conductor would have occasioned instant death—the stream of fluid far exceeding anything I ever witnessed, excepting during a thunderstorm. Had the insulators been dry, what would have been the effect? In every acre of fog there was enough accumulated Electricity to have destroyed every animal within that acre. How can this be accounted for? How much have we to learn before we can boast of understanding this intricate science?"

It is not improbable, as has been asserted by some, that the sacred fire, drawn down from heaven by Prometheus, was lightning. Some even go so far as to assert that the ability of thus drawing down lightning from the sky was known in remote antiquity to the priests of various nations, who made use of such knowledge to inspire the worshippers with reverence. Some of the earlier Romans were thus credited with this knowledge. Numa Pompilius is said to have thus drawn down the sacred fire on a number of occasions with entire safety. Tullus Hostilius, after having read some notes left by Numa on the sacred art of thus worshipping Jupiter Elicius, attempted to repeat the sacred worship, but, departing from the rules of the holy rite, aroused the ire of Jupiter, and was struck dead by a lightning flash. According to another account, one of the kings of Alba was killed by a bolt from heaven while performing a similar ceremony. Ovid thus refers to this fact: "*Fulmineo periit imitator fulminis ictu.*" *

Some alleged early electricians.

* "In imitating thunder, the thunderer perished."

Probable variety of causes for atmospheric electricity.

Atmospheric electricity, the name generally given to the free electricity of the air, has been ascribed to a variety of causes, such as the evaporation of water; the friction of air particles against one another, against water globules in the atmosphere, or against the earth's surface; to differences of temperature, etc. It is possible that besides the above, all of the many other physical processes, which are constantly going on in nature, act conjointly, to a greater or less extent, in imparting both to the atmosphere and to the earth, the opposite electric charges, which they are always found to possess.

Pouillet's theory of atmospheric electricity.

Volta was the first to suggest that the free electricity of the air was due to the evaporation of water. Other physicists made investigations in this direction. Of these, the studies of Pouillet were the most complete. This physicist pointed out the necessity for the existence of saline substances dissolved in the water, showing that the evaporation of pure water was not attended by the production of any electric charge. But what is peculiarly suggestive in Pouillet's conclusion, is that the evaporation of ocean water, that is, of water containing a large percentage of common salt in solution, produces a marked electrification of the air, the vapor being positively charged, and the vessel containing the water negatively charged. When we bear in mind the vast extent of the ocean surface, and the immense amount of evaporation that is constantly taking place every day, we can see the significance of Pouillet's observation on one of the possible causes for the free electricity of the air, since this would account, at least in part, both for the positive electricity of the atmosphere and the negative electric condition in which the earth is generally found.

Evaporation of water of ocean probably main cause.

Pouillet observes that even in the case of fresh waters, such as those of rivers and springs, there is present a sufficient quantity of dissolved saline matters to cause the vapors arising from their surfaces to acquire a small positive charge.

Sylvanus P. Thompson coincides with Pouillet in the belief that the free electricity of the atmosphere is due, at least in part, to this evaporation that constantly goes on from the ocean's surface.

Sylvanus P. Thompson.

Among modern philosophers, probably none have given greater attention to atmospheric electricity than Prof. Oliver Lodge, who points out the fact that the production of electricity by the friction of air against water is, to say the least, improbable. He questions the opinion expressed by some that the motion of the dust particles against the air constitutes the principal cause. He acknowledges, however, that if this be one of the causes, it is constantly acting, and that the effect of a shower of rain must be to carry down to the earth some of the charge accumulated during dry weather.

Lodge on atmospheric electricity.

Pointing out the well-known fact that during all severe atmospheric disturbances, such as cyclones, tornadoes, and thunder-gusts, a rotary or whirling motion of the wind is known to exist, Lodge suggests that, if in thunder-gusts the axis around which this rotary motion occurs be regarded as horizontal, there would then be produced, by such an action, an arrangement not unlike that of an ordinary cylindrical frictional machine, with the earth acting as a rubber and the upper regions of the atmosphere as the prime conductor; that the air electrified by friction against the earth in the whirling motion carries

Lodge's ideal natural electric machine.

the charges so produced into the upper regions of the air, where it discharges them, again approaching the surface of the earth by condensing, where it is recharged by friction. He also suggests that in all storms the wind driving a spray of mist against the earth's surface may produce, on a large scale, a natural type of Armstrong's hydro-electric machine.

Peltier's theory of atmospheric electricity.

Without going further into the theories concerning the production of the free electricity of the air, we will call brief attention to the theory of Peltier, which is, perhaps, more generally held by philosophers than any other. Peltier believes that the presence of the free electricity of the atmosphere can be explained by the inductive action of the earth on the conducting stratum in the higher regions, through the non-conducting layer of air that lies between the two. It is a known fact that the surface of the earth possesses a permanent negative electric charge, at least negative when compared to the condition of the air outside it. If Peltier's theory be correct, then the negative earth, acting inductively through the non-conducting layer of atmosphere, would produce negative charges in the upper conducting regions of the air by induction.

Kelvin on atmospheric electricity.

Kelvin (Sir William Thomson) shows, by actual measurements in a number of localities, that the entire surface of the earth is negatively electrified, and that the electrification varies both at different times and in different localities. During rainstorms, the earth's surface may become positively charged. Although Kelvin does not agree with Peltier in all his conclusions, yet he believes that an inductive action does take place between the generally negative earth and the upper conducting regions of the atmosphere.

If the inductive theory be true, then the inhabitants of the earth are in the curious position of living in the dielectric of a huge Leyden jar, of which the earth and the sky are the two coatings, and the non-conducting air the dielectric. When we say the sky we mean the higher conducting regions of the atmosphere. This conducting layer is, probably, to be found at a height of less than twenty miles above the level of the sea. Whenever the opposite charges become sufficiently powerful the intervening dielectric is broken, and the discharge takes place. Ordinarily, the distance of, say approximately, twenty miles, which we assume represents half the thickness of the dielectric, is too great to permit this sparking to take place, but every now and then, from one cause or another, portions of the charge on the upper coating are carried downward as clouds, and, when they approach near enough, disruptively discharge either to the earth or to neighboring oppositely charged clouds.

The earth's huge Leyden jar.

It is a fortunate circumstance that neither of the coatings of this great Leyden jar are good conductors of electricity; for, as we have seen, when the discharge of a Leyden jar occurs, the presence of the opposite metallic coatings, which are excellent conductors of electricity, ensures the almost complete discharge of the dielectric in one single flash. We say almost complete discharge, because although, as we have heretofore pointed out, a residual charge does occur, yet it is quite small compared with the initial discharge. Were the earth's Leyden jar furnished with good conducting coatings, the entire charge existing on the earth, and its opposite coating of fairly conducting stratum of air, would take place in one single, awful crash, the effects of which are appalling to contemplate.

Why the earth's discharges are local, and not general.

Electric observatories.

Neither the insulated rod of Dalibard, nor the electric kite of Franklin, are suited for continuous observations on the free electricity of the atmosphere. Regular electric observatories are established for the study of these phenomena, and various forms of instruments are employed, especially devised for this particular purpose. We will describe a few only of these instruments.

FIG. 53.—Peltier's Electrometer for Studying Atmospheric Charges. The scale divisions are marked both at the top and bottom of the glass cage. In reading the angular deflection of the needle, the eye is placed so that the deflected needle points to the same scale division in both the upper and the lower scale.

Saussure's electrometer.

Saussure employed a form of pith-ball electrometer, in which the pith-balls were replaced by two straws. This instrument was protected from the rain by a metallic cap, placed on the top of the inclosed glass cage containing the straws. The divergence of the straws, which marked the potential of the charge, was read by means of a graduated scale. A more or less elongated metallic rod, pointed at its upper extremity, surmounted the instrument. Volta improved this form of instrument by placing a piece of lighted

tinder at the upper extremity of the pointed conductor. This had the effect of extending the action of the rod, from the fact that the heated smoke acted as a conductor, thus permitting the column to collect electricity from the air at a greater height.

Peltier's electrometer.

Peltier devised an electrometer which he employed in his researches on atmospheric electricity. In Peltier's instrument, as shown in Fig. 53, the pith-balls and straws of the other electrometers are replaced by a light metallic needle, *bb*, supported in a horizontal position on a vertical pivot. To this metallic needle is rigidly attached a small magnetic needle, *aa*. Both needles are suspended inside a metallic ring, attached to the lower end of the vertical metallic stem which passes through the top of the instrument. At the upper end of this stem are attached a metallic conical shade to screen the instrument from the rain, and a hollow metallic ball, provided for receiving the charge. Below *bb* another larger needle, *cc*, is supported by the same pivot as *bb*.

Description of electrometer.

Manner of using electrometer.

In use, the electrometer is placed so that the large needle is in the same vertical plane as the magnetic meridian; in other words, the instrument is so placed that *cc* points in the same direction as the magnetic needle, *aa*, when it comes to rest. The globe of the electrometer is then charged inductively from the air by connecting it momentarily with the ground, while under the inductive influence. The charge thus imparted will, of course, be of the opposite polarity to that producing it. This charge causes a repulsion of the needle, which is read off on the graduated scales provided for that purpose.

It will be noticed that in the above instrument the force of repulsion is measured as being opposed,

Repulsive force opposed by magnetic attraction.

neither by the twisting of a metallic thread, as in Coulomb's torsion balance, nor by the force of gravity, as in the pith-ball or straw electroscope, but as against the force of magnetic attraction with which the earth acts on the magnetic needle, *cc.*

The exploring conductor, employed at the Meteorological Royal Observatory, at Greenwich, is

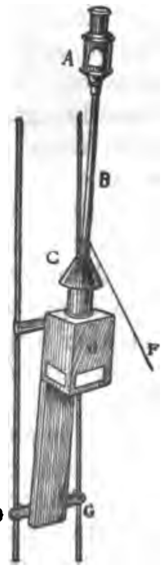


FIG. 54.—Exploring Conductor of the Greenwich Royal Meteorological Observatory. The wire F carries the charge collected from the atmosphere to the instruments in the observing-room.

Exploring conductor of Royal Meteorological Observatory, at Greenwich.

shown in Fig. 54. Here B is a copper rod, on which slides a lantern, A, containing a constantly burning lamp. This rod is supported at its lower end by an insulating cone of glass, placed in a wooden compartment, *d,* kept dry by the heat of another constantly burning lamp. The glass cover is protected from the rain by a conical copper screen,

shown at *c*. A wire, F, in electrical connection with the copper rod B, extends to the electrical instruments in the observing room. G G are iron rods on which the apparatus can slide up and down, thus permitting observations to be taken at varying heights.

Observations on atmospheric electricity, by the United States Weather Bureau.

The United States Weather Bureau has made a number of observations on atmospheric electricity, both by means of kites and by exploring conductors. Their first kite experiments were made in 1885, at Blue Hill Observatory, some ten miles southeast of Boston. They employed for this purpose ordinary kites of a hexagonal shape, raised by means of strong hempen fish-line, which was rendered better conducting by a loosely wrapped, bare, thin copper wire. They employed in these experiments a variety of quadrant electrometer, one pair of opposite quadrants of which were charged with a positive charge of 500 volts, and the other pair with a negative charge of 500 volts.

Box or Hargrave kite.

The influence of the height of the kite on the voltage of the charge was shown by the fact that any one observing the indications of the electrometer could tell, without looking at the kite, whether it was rising or falling; for, as the kite rose in the air, the electrometer needle moved in a direction indicating an increase in its charge, and when the kite fell, it moved in the opposite direction. Later on, in these investigations, the Weather Bureau employed the box, or Hargrave kite. This well-known form of kite lends itself to such investigations better than the ordinary kite by reason of its greater steadiness. When properly managed, it remains fairly steady at any given elevation.

The part played by the clouds in lightning phe-

Part played by clouds in lightning phenomena.

nomena is unquestionably that of moving conductors, which collect the charges from the air, and discharge them either into neighboring clouds or into the earth. In addition to this, it is probable that the clouds also act to carry down the free charges from the higher conducting regions of the atmosphere to the lower strata.

Free atmospheric electricity generally positive.

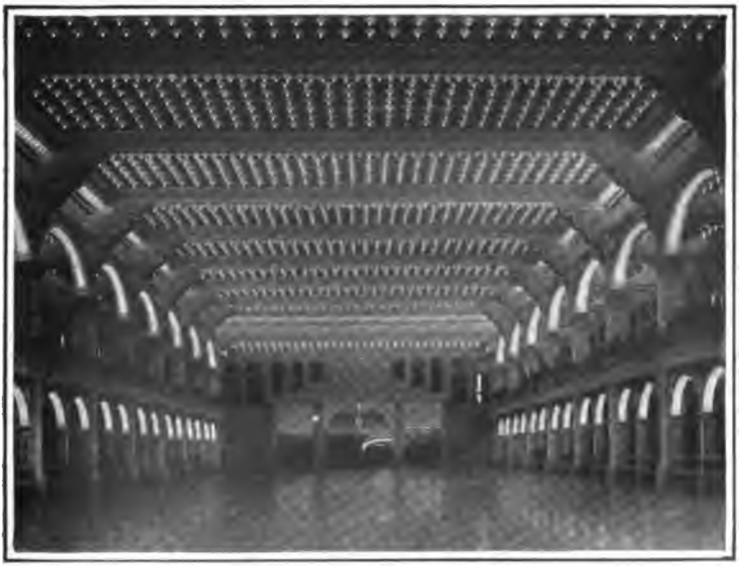
Although the free electricity of the air is generally positive, yet, as we have seen, it changes rapidly to negative on the approach of clouds and fogs. Clouds may, therefore, be either positively or negatively charged, as indeed the discharges occurring between neighboring clouds demonstrate, since, in all such cases, these charges must be of opposite signs.

The lightning flashes attending a thunder-gust are simply efforts on the part of nature to regain a condition of electric equilibrium in the atmosphere by the neutralization of the opposite charges on neighboring clouds, or of the opposite charges on the clouds and the earth. As soon as this neutralization is accomplished electrical manifestations of the storm are over.

Robert von Helmholtz and dark, lurid thunder-clouds.

The peculiar dark and lurid appearance of what are popularly called thunder-clouds has, probably, been noticed by all. It is interesting to state, in this connection, that we now have scientific reasons for being convinced that the popular belief of these clouds being especially charged with electricity is correct; for an observation, made by Robert von Helmholtz, shows that the opacity of a cloud of steam is at once markedly increased if a convective electric discharge is caused to pass into its mass. Just how this electric charge acts is uncertain. It

By courtesy of the New York Edison Company



EXAMPLES OF BRILLIANT ILLUMINATION
The upper picture shows Broadway, New York City, on a rainy night. The blaze of electric lights and signs has well earned this street the title of "The Great White Way." The lower picture shows the ballroom of "Dreamland," Coney Island, profusely illuminated

is most probable, however, as Lodge has pointed out, that its action is not unlike that which Aitken has shown to exist in the formation of dew and rain; viz., that the condensation of the water vapor of the air takes place on minute nuclei or small central portions of dust particles that are to be found in the atmosphere at practically all times. Whether, however, in the case of the cloud of steam, the nuclei be dust nuclei, or metallic nuclei formed by small particles of metal torn off from the electrodes during a discharge, we are unable to state. It would seem probable, however, from some very recent observations, that they consist of metallic nuclei, composed of electrons or atomic fragments torn from the electrodes during the discharge.

Lodge and Aitken on cloud nuclei.

Possible presence of electrons in thunder-clouds.

Various speculations have been advanced to account for the exceedingly high potential of the lightning flash. One of the most generally received of these attributes the high potential to the union or coalescence into a single drop of the numerous minute drops of water with which all clouds are formed. The charges of the minute drops of water that form clouds, like all electric charges, reside on the surfaces of the drops. When, therefore, several thousands of these drops coalesce, or unite to form a single rain drop, the area of the combined drop is enormously smaller than the sum of the areas of all the combined drops. The density of the electric charge on the rain drop is, therefore, correspondingly increased with, of course, an attendant increase in the electric pressure or electromotive force. Tait, in a lecture on thunderstorms delivered in 1880, has expressed his doubt as to the correctness of this explanation.

Suggested cause of high-potential of lightning flash.

The form of apparatus shown in Fig. 55 is in-

Experiment with insulated metallic curtain charged when unrolled and then rolled up.

tended to illustrate this principle. A metallic curtain, suspended as shown, is provided with an insulated handle, by means of which it can be rolled or unrolled something like an ordinary curtain. The shade or curtain is wrapped on the surface of a metallic cylinder, by means of which it is in electric connection with the quadrant electrometer shown at the upper left-hand corner of the figure. If now, while the curtain is unrolled, a feeble electric charge is imparted to it, scarcely sufficient to cause the pith balls to move apart, the increase in

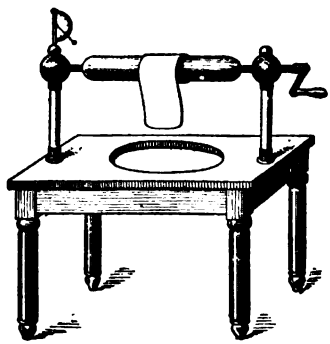


FIG. 55.—Suggested experiment to show how lightning discharges acquire their exceedingly high electric potential.

the electric density of this charge, which will occur when the curtain is rolled up, and the extent of its outer surface is thus decreased, will be at once evident by the violent repulsion of the pith ball of the quadrant electrometer.

Diurnal changes in quantity of free electricity in the atmosphere.

The amount of free electricity in the atmosphere is subject to daily variations. Without going into detailed descriptions of these variations, it is sufficient to say that in the Northern Hemisphere, between latitude 40 and 55 degrees, there are, during

every twenty-four hours, two periods when the electric charge is greatest, and two periods when the electric charge is least. Though varying somewhat with the season of the year, the two maxima occur a few hours after sunrise and a few hours after sunset, and the two minima, a short time before sunrise and a few hours before sunset. There are, also, annual changes, the charges increasing in intensity from July to December, when they again begin to decrease.

It has frequently been noticed, during a thunderstorm, that a peal of thunder is almost immediately followed by unusually large drops of rain. This effect is popularly ascribed to the agitation or shaking of the air by the thunder, causing a number of smaller drops of rain to unite into larger drops. The phenomenon, however, is an electric one, and is caused by the lightning flash and not by the accompanying thunder peal or crash in the atmosphere.

Larger drops of rain follow thunder-clap.

If a large jar or other space, filled with dust, smoke particles, or the minute water particles produced by condensed steam, has a brush electric discharge sent into it, an exceedingly curious effect will be produced. Almost instantly the space will be cleared of its dust, smoke, or water particles, which will be observed to rush together and rapidly coalesce or unite in large particles, which either fall to the bottom of the jar by their weight, or are driven to the walls of the space, to which they adhere. As we shall see in another volume, the fact that electric discharges possess the force of causing finely divided matter to coalesce or cohere is employed in wireless telegraphy.

Clouds of vapor, smoke and dust dispelled by electric charges.

It is not, at first sight, very clear just why this

electrical aggregation of finely divided matter takes place. Electric charges of the same name, as we have already seen, repel each other, but here the presence of an additional, or outside, charge results in the mutual attraction of the particles. The following experiment of Rayleigh, however, may make it more readily understood. Every one knows the characteristic fan-like shape of a vertical water-jet, such, for example, as that formed by an ordinary garden hose. Although, near the nozzle, the jet has a clear, rod-like appearance, yet near its extremity it loses its transparency, becomes turgid, and spreads out in a fan-like form. Now, Rayleigh has shown that an electrified rod of sealing-wax brought near such a jet will, even while a yard or more distant, cause a remarkable change to take place, both in the size and in the general appearance of the jet, which shrinks on itself, while the brush-like appearance, at the top, almost entirely disappears.

Rayleigh on the phenomena of electrified water-jets.

Rayleigh found, on carefully examining such a jet by means of intermittent flashes of light, that the fan-like expansion of the unelectrified jet was due to a scattering of the separate particles of the water when they collided or struck against one another, the separate particles rebounding from one another, instead of uniting to form larger drops. He showed, however, that this rebounding only occurred while the separate water particles were at the same electric potential, and that, if a small difference of potential was produced in some of them, as by the approach of the rubbed sealing-wax, that the colliding particles then immediately united or coalesced, and so increased in size, altering the entire appearance of the jet. In the same way, the discharge of the charged cloud, consisting as it does

Examination of electrified water-jets by intermittent flashes of light.

of numerous water particles, producing a slight difference of potential between these particles, causes them instantly to coalesce on colliding, and thus to produce the large rain drops that occur during thunderstorms, almost immediately after a lightning flash.

Lodge on relation between electric condition of atmosphere and the weather.

Lodge points out, in this connection, the possibility of weather changes being more dependent on the electrical conditions of the atmosphere than has hitherto been thought probable. He suggests that the uniformity of the electric potential of the small cloud particles would necessarily result in the formation of a fog, while the establishment of a small difference of electrical potential between them would necessarily result in precipitation, and, consequently, clearing weather.

CHAPTER IX

LIGHTNING AND THUNDER—PROTECTION AGAINST LIGHTNING STROKES

"The problem of (lightning) protection, therefore, ceases to be an easy one, and violent flashes are to be dreaded, no matter how good the conducting path open to them."—OLIVER LODGE

When lightning flashes occur.

AS we have already seen, when the difference of potential, or electric pressure, between neighboring clouds, or between a point on the earth's surface, and a point on a neighboring cloud, becomes sufficiently great, the tension of the intervening dielectric, or air, is relieved by a rupture or smashing of the air between these points, and a lightning flash occurs. It is a popular mistake to believe that this action takes place between some particular point on the earth, such as a tall building, and a corresponding point on the approached cloud. Such an idea is quite erroneous; the action, in reality, takes place between an extended area on the earth's surface and a correspondingly extended area, possibly of several thousand acres of charged clouds. Lightning flashes, therefore, necessarily discharge large areas, both of the earth's surface and of the surfaces of the opposed cloud. In addition to the flash that can be seen, as marking the passage of the discharge, there is also a rush of electricity both over the surfaces of the cloud and over the earth's surface, between the two points of discharge. This rush-

The visible part of a lightning flash but a small part of the phenomenon.

ing of electricity along these two conducting surfaces is very apt, as Lodge points out, to set up a condition of affairs liable to produce secondary lightning flashes.

Lightning strokes assume a variety of forms which we will now briefly discuss. Forked lightning, or

FIG. 56.—Forked Lightning. Note that the alleged zigzags or sharp angular bends are wholly absent in the photograph. Even when examined by a magnifying glass the bends are rounded, like those of a meandering river channel in the lower course of the stream.

the so-called zigzag lightning, is, perhaps, the most characteristic of all lightning flashes. It is a popular error to believe that such flashes pass over angular or zigzag paths. Photographs of forked lightning show clearly that there are no sharp angular bends, but that the flash follows a winding, meander-

Forked or zigzag lightning.

ing course, very similar to the bendings or windings of a river channel. Fig. 56, photographed by John M. Justice of Philadelphia, shows lightning flashes of this type, in which the rounded bends are clearly seen, and in which no sharp or angular zigzags can be detected. A lightning flash occurring between the clouds is shown in Fig. 57, that is also reproduced from photographs by Mr. Justice. Some forms of lightning discharges between the clouds

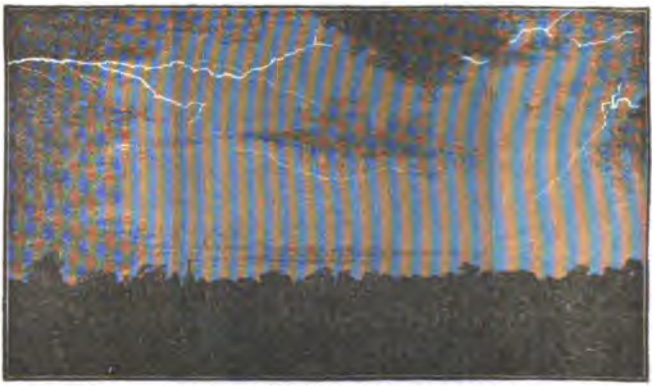


FIG. 57.—Lightning Flash between Neighboring Clouds.

and the earth are shown in Fig. 58, also reproduced from photographs by Mr. Justice. The faint branches in these discharges are very marked.

Sheet or summer lightning.

Sheet lightning is the name given to a variety of lightning in which an expanded flash appears, lighting up the surfaces of the surrounding clouds. Sheet lightning is probably due to the reflection of light from the clouds of a lightning flash that has occurred too far off from the observer to permit the thunder to be heard. Such flashes are, therefore, unaccompanied by thunder. This form of lightning

is sometimes called summer lightning. In sheet lightning the outlines of the clouds are momentarily illumined by the flashes.

Globular lightning is a rare form of lightning, in which the discharge assumes the form of a globe of light, which either remains stationary in the air or moves slowly through it and then disappears, generally with a loud explosion. Globular lightning is a comparatively rare phenomenon. A case is on record where a large ball of fire came down the

Globular or ball lightning.

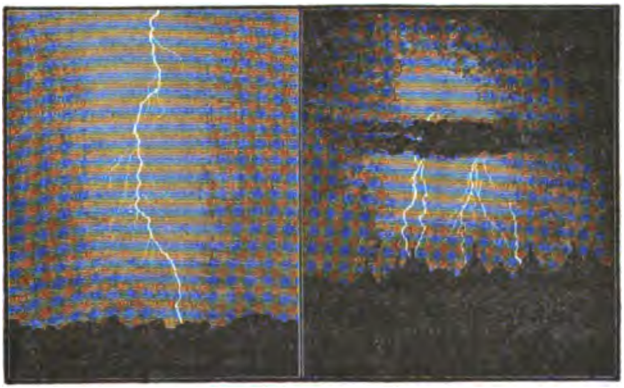


Fig. 58.—Lightning Flashes between the clouds and the earth.

chimney of a small house, entered the room, and rolled slowly across the floor. It then gently rolled out through the middle of the room and disappeared through a crack in the wall. Although several people were present in the room, yet no injury was done.

Another appearance of globular lightning is thus related by Noad:

Description of globular or ball lightning seen at sea.

"At four P.M., a great deal of wind; lightning and heavy black clouds passing over head; at half-

past six a *ball of fire struck the mainmast,* passed through the upper deck, making a hole about eighteen inches in diameter and four feet from the mast, when it exploded on the gun-deck with a tremendous noise, and forcing the deck upward abaft the mainmast. About a quarter past seven another ball of fire struck the mainmast, and ascending upward and passing through the centre of the mast, it exploded with a loud crackling noise like the roll of musketry, with vivid sparks, breaking several of the large iron hoops which surround the mast, and scattering the fittings in all directions. A sailor, on approaching the hole on the deck, was scorched so severely from *below upward* that he died twelve days after in extreme agony. The compass was not affected, nor was there any smell."

Plante on globular lightning.

From some experiments made by Planté in a form of battery called a secondary battery, which we will discuss in another part of the book, the globe of fire appears to be formed by rarefied incandescent air, or gas, resulting both from the decomposition of the water vapor and from its high temperature.

Possible explanation of the cause of globular ligtning.

The highly important facts that have been recently discovered concerning the possibility of electric discharges tearing off minute fragments from the atoms of ordinary matter, and forming therewith an extremely tenuous kind of matter, possessing properties peculiar to itself, render it not at all improbable that the long sought for explanation as to the cause of globular or ball lightning may be found in the formation, under the powerful action of lightning flashes or discharges, of small quantities of intensely heated and highly charged matter, formed from disassociated atoms. Such matter

would possess the exceedingly light and highly rarefied condition that Planté pointed out as necessary for the nucleus or central portion of globular or ball lightning. Moreover, the great stability that the atoms of ordinary matter possess, a stability so great that it has only been recently that their disassociation or tearing apart has been believed possible, would appear to indicate a corresponding degree of intensity with which such matter would tend to recombine, and again enter into its more stable form as ordinary matter. Both the levity of the globes of fire, as indicated by the ease with which they float about in the air, and the intense force with which they generally explode, as manifested by the destructive effects they produce around them, and the loud reports attending their breaking up, would seem to render this explanation quite possible, the explosion being probably due to the energetic recombination of the disassociated atomic matter, as soon as it loses its high temperature or other condition which prevents the fragmental atomic matter from recombining. This fifth state of matter, therefore—viz., that state or condition of matter in which it manifests the phenomena of radio-activity, and which may be called corpuscular, electronic matter, or fragmental atomic matter—may possibly have to do, not only with the phenomenon of ball lightning, but with some of the phenomena of lightning and thunder generally, as we shall hereafter discuss.

Globe lightning possibly a mass of glowing disassociated atoms.

A fifth state of matter.

Corpuscular or electronic matter.

Multiple or ribbon lightning is a very rare form of lightning, in which the discharge takes the shape of a number of separate parallel discharges, which gives the flash the general appearance of a ribbon. Such a lightning flash is shown in Fig. 59, photographed by John M. Justice of Philadelphia. Here

Multiple or ribbon lightning.

there are fourteen distinct discharges separated from one another by dark spaces.

Bead lightning is another rare form of lightning. It appears, in the opinion of Planté, to be a kind of transition form between forked or zigzag lightning and globular lightning.

FIG. 59.—Multiple or Ribbon Lightning, photographed by John M. Justice. Note here the error of the popular belief that lightning never strikes twice in the same place. Note, too, the marked parallelism of the separate strokes.

Thunder-storms or thunder-gusts.

Any rainstorm that is attended by thunder and lightning may properly be called a thunderstorm. There are two distinct types of such storms; viz., those which occur late in the afternoons or in the early evenings of hot sultry days, and which are, therefore, sometimes called heat thunderstorms or thunder-gusts; and those which accompany the great

storms in the United States that begin in the west and travel toward the east. Both of these storms have a progressive motion. It is not, however, well marked in heat thunderstorms, which cover but a limited territory.

Some characteristics of a passing thunderstorm, after Davis.

The passage of a thunderstorm is well described by Davis, in his work on "Elementary Meteorology," from which the following description is condensed. The beginning of the storm, as shown in Fig. 60, is heralded by an appearance in the west, during the afternoon of a hot day, of a forerunning layer of cirro-stratus cloud, a name given to one of the fleecy, feathery clouds that occur in horizontal bands or

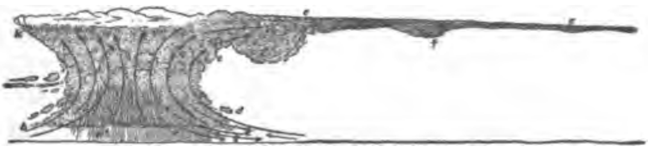


FIG. 60.—Phenomena of a Thunder-Gust. The arrows show the directions of the wind.

layers in the higher regions of the atmosphere. The forward edge of the cirro-stratus cloud is thin, fibrous, and hazy in appearance. As it advances, it grows thicker at its opposite end, and festoons of clouds slowly descend and dissolve from its lower surface, as the great rain-bearing cloud mass approaches. The cirro-stratus cloud may extend from ten to fifty miles in advance of the rain cloud. The air is oppressively hot before the storm, but grows slightly cooler as the forerunning cloud hides the sun. "Thunder-heads," or rounded masses of dark, lurid clouds, which, as we have already seen, indicate heavily charged masses of vapor, may be seen rising in the west an hour or so before the forerun-

Appearance of dark, lurid, thunder-heads.

ning sheet of cirro-stratus clouds advances above them. Distant thunder is heard as the thunder-heads approach, and then, below their level base *b*, may be seen the gray rain-curtain *r*, which trails the ground and hides all objects behind it. Small detached clouds *d*, frequently form in front of the main cloud mass, and rapidly increase in size until they merge with the storm cloud, which, moving more rapidly toward the east, overtakes them. A ragged "squall cloud" *s*, of a light gray color, rolls beneath the great dark cloud mass, somewhat behind its forward edge.

Appearance of gray rain-curtain.

Formation of the squall cloud.

The whole mass of storm cloud now advances broadside across the country with a velocity of from twenty to fifty miles per hour. Below the clouds, and in front of the rain, is the short-lived, outrushing wind squall *g*, that carries with it clouds of dust. During the storm the temperature may fall from ten to twenty degrees in half an hour or less. The first drops of rain are large, falling in pelting drops, but these soon change to a heavy downpour, often accompanied by hail. The moisture in the air increases; vivid lightning flashes occur with loud thunder, and as the storm centre comes more nearly overhead, the intervals between the lightning flashes and the thunder become less; the dark shade in front of the storm grows less marked; the lightning flashes become less frequent, and a larger interval occurs between them and the thunder, until, at last, the storm passes, the rain ceases, the clouds break in the west, the clear blue sky appears, and the air grows cooler, dryer and cleaner. These storms do not appear to have a definite path of progression. Moreover, they are relatively local disturbances.

Arrival of out-rushing wind-squall.

Arrival of the storm directly overhead of observer's region.

Cessation of storm.

All thunderstorms of this description are caused

by ascending currents of warm, moist air, that take place over heated areas, where the pressure of the atmosphere is reduced, and, therefore, where the barometer is low. The moist, heated air rushes in from all sides toward the area of low pressure, and, becoming chilled by the cooler upper and rarer regions of the air, as well as by its expansion in such regions, has its moisture rapidly condensed as rain. The heat, liberated during this condensation, serves to carry the moist air into still higher regions. The inflow of moist air from below increases the quantity of electricity in the cloud, and, finally, the electric potential, or pressure of the charge in the cloud, increased by the union or coalescing of the numerous cloud particles into rain drops, continues until a discharge takes place from the cloud in the form of a lightning flash.

Genesis of thunder-storms or thunder-gusts.

The cloudbursts of the arid districts in the western part of the United States are exaggerated forms of thunderstorms. They continue but for a very short time, and do not cover a great extent of territory. Over the limited area, however, the rainfall is so excessive that dry stream channels are suddenly filled with roaring torrents. In the United States all the thunderstorms advance across the country from west to east with a varying velocity of from twenty to fifty miles an hour.

Cloud-bursts.

The cause of the outrushing thunder-squall, with its accompanying dust clouds, has been attributed by some to the action of falling rain. This, however, can not be true, since such squalls frequently occur under clouds from which no rain is falling. The true cause is, probably, the reaction or kick produced by the sudden upward expansion of the mass of rising air. The details of the lower part of Fig. 60

Origin of out-rushing thunder-squall.

are shown in Fig. 61. Here, as before, the arrows indicate the direction of the wind.

Results of observations of United States Weather Bureau on thunderstorms.

The United States Weather Bureau has given considerable attention to the study of the thunderstorms of the United States, and has already been able to make forecasts of coming thunderstorms, sufficiently accurate to be of value to the agricultural interests of the country. The following conclusions have been reached by the Weather Bureau; viz.—(1) That

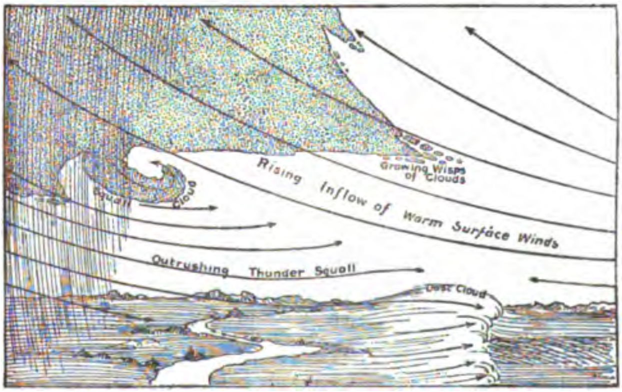


FIG. 61.—Phenomena of a Thunder-Gust.

thunderstorms progress or travel in well-defined areas from the Mississippi toward the east; thus affecting fairly extended areas. (2) That, in addition to such storms, there are sporadic storms; *i.e.*, isolated or separate storms that cover but a limited territory. (These are the heat thunderstorms already alluded to.) (3) That thunderstorms occur in districts which have been covered by previous storms on the same date. (4) That thunderstorms frequently die out during the night and come into action again during the next day, but in a region or

district further to the east. (5) That therefore it should be possible successfully to predict thunderstorms.

It is a fact well known to meteorologists, who make a study of storms and other phenomena of the atmosphere, that nearly all the great storms of the United States are travelling storms, that are attended by a rotary or whirling motion of the wind, and that such storms move broadside across the country from west to east. It is largely on account of this fact that it is a comparatively easy thing for the United States Weather Bureau, when such a storm has once developed, and is moving eastward, to foretell when it will reach a certain part of the country. The only uncertain elements in such a forecast are the exact path the storm will take and the rate at which it will move across the country. Now many thunderstorms that occur in the United States are of this type, and attend or move with such rotary storms; or, as they are more frequently called, cyclonic storms. Mohn, therefore, divides thunderstorms into two classes; viz., heat thunderstorms, above mentioned, and cyclonic thunderstorms. It is possible, however, that all thunderstorms partake to some extent of the conditions of both of the above. To Mohn's classes of thunderstorms, as given above, there should be added winter thunderstorms. These thunderstorms are also of the cyclonic type.

Elements of uncertainty in thunderstorm forecasts.

Mohn's classification of thunderstorms.

According to the observations of the United States Weather Bureau, thunderstorms occur with considerable frequency over all the United States east of the one hundredth meridian of longitude. To the west of this meridian, except in the Rocky Mountain regions, their frequency decreases, reach-

ing a region of practically no storms along the immediate Pacific Coast.

Map of frequency of thunderstorms in the United States.

In Fig. 62, taken from Bulletin No. 30 of the United States Weather Bureau, is shown the average number of thunderstorms occurring each year in the United States. An inspection of this map will show that there are three regions where thunderstorms are especially numerous; viz., one over Florida, where forty-five of such storms usually occur every year; one in the middle Mississippi Valley, where there

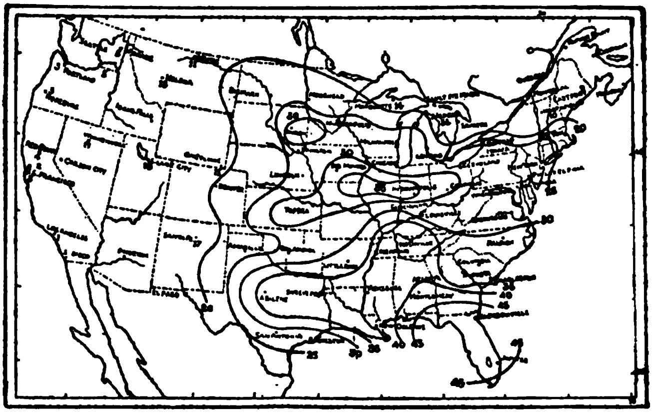


FIG. 62.—Map of the United States, showing the average number of thunderstorms that occur annually.

are about thirty-five thunderstorms per year; and the third in the middle Missouri Valley, where there are thirty such storms annually.

Statistics of number of people killed or injured in the United States by lightning strokes.

The United States Weather Bureau has made a careful investigation of the number of people killed by lightning strokes in the United States. From these observations it appears that during 1900 713 people were killed. Of these, 291 were killed in the open fields or on the highways, 158 were

killed in houses, 57 under trees, and 56 in barns. The circumstances attending the death of the remaining 151 are unknown. Besides those killed outright, 973 were more or less injured by lightning strokes during this period. Of this number some 327 were injured while in houses, 243 while in the fields, or on the highways, 57 in barns, and 29 under trees. The circumstances attending the injuries of the remaining 317 are unknown.

Places where people were killed or injured by lightning strokes.

It will be seen from the preceding that a great variety of external circumstances attend the loss of life or injury from lightning strokes. It must not be supposed, however, that the number of deaths or injuries indicate necessarily the relative positions of danger. Because more people either died or were injured while in houses does not show that such are positions of the greatest danger, since, of course, account must be taken of the fact that more people were naturally in houses during such storms than out on the highways, or in the fields. Of the people who were killed while under trees—a most dangerous place during lightning storms—it is quite possible that none of them would have been injured had they remained out on the highways or in the open fields.

Circumstances affecting liability of death or injury from lightning strokes.

Henry points out, in Bulletin 30 of the United States Weather Bureau, that the chances of being struck by lightning depend on the frequency of the lightning stroke for a given area of country, while the total number of cases depends both on the frequency of the lightning stroke and the density of the population. Necessarily, the number of strokes that fall in any one State each year must depend on the number of square miles in the area of such State, while the number of people the strokes killed

or injured must necessarily be greater the greater the number of people that are exposed to such strokes. Thus, in Fig. 63, the geographic chart of the United States, is given the number of fatal cases of lightning strokes in the United States per year for each ten thousand square miles of area. It will be noticed, by a comparison of this chart with the chart which gives the average number of thunder strokes in the United States per year, that in the Gulf States, although the average frequency

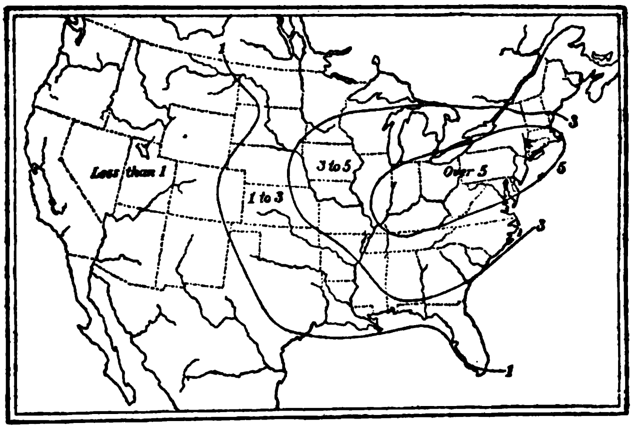


FIG. 63.—Chart of the United States, showing the number of fatal lightning strokes per year for each 10,000 square miles of area.

Why average number of deaths by lightning is greater in New England States than in Florida.

of thunderstorms is highest, yet the average number of deaths from lightning strokes is low, being only one, while in the New England and adjoining States, where there are probably only half as many thunderstorms, the death rate is higher. This is, of course, due to the fact that there are a greater number of large cities in these States than in the Gulf States.

As a rule, it appears that the liability to be struck by lightning is greater in the country than it is in

the city. This is, probably, due to the fact that in the city the modern building, with its steel frame and metallic roof, is a far better conductor of electricity than the ordinary wooden or stone house of the country. Then, too, the great number of overhead wires for telegraphic, telephonic, or electric light and power transmission, afford protection by acting as lightning guards or protectors.

Liability to lightning stroke greater in the country than in the city.

The possibility of protecting people and houses from the destructive effects of lightning strokes suggested itself to Franklin's practical mind, as soon as he had demonstrated the identity of lightning flashes and electricity by his famous kite experiment in 1752. Noting the readiness with which a pointed conductor is deprived of its charge by means of convective discharges, he conceived the idea of protecting buildings by erecting on one of the outside walls a conducting rod of such material and area of cross-section as would be able to permit it to safely carry to the earth the most powerful lightning stroke that was apt to occur in that particular latitude. He gave instructions for such a conductor, that it should terminate at its upper extremity with one or more points, and that its lower extremity should extend downward until it met permanently moist earth, possessing good powers of electric conduction. The similarity of structure between this first lightning rod, and the best of those devised at the present time, speaks highly of the mastery which Franklin had gained over this most difficult subject at so early a date as 1752.

Franklin's invention of the lightning rod.

Franklin's directions as to construction and location of lightning rods.

It is unfortunately a well-known fact that, at times, no matter how carefully a lightning rod has been constructed and erected, there occasionally occur, and very fortunately only occasionally, flashes

Lightning rods do not always protect buildings on which they are placed.

between the sky and the rod that are so great that the rod is unable to afford protection and that for the purposes of such particular strokes a lightning rod is absolutely worthless. Such facts have even given rise to the idea that all lightning rods are worthless, an idea that is unquestionably both untenable and unscientific.

Lightning flashes that hold ordinary lightning rods in contempt.

It will be a matter of interest to inquire more carefully into the exact nature of those rare lightning discharges that occur now and then, and against which the lightning rod is unable to afford protection, no matter how carefully made. At the outset of such a question it would be well to frankly acknowledge that much yet remains to be discovered concerning the exact nature of these, fortunately, rare lightning discharges, although, indeed, many of their peculiarities are now fairly well known.

Lodge's classification of lightning flashes.

Lodge arranges all lightning discharges that occur between earth and sky into two classes; viz., steady-strain discharges, where the strain in the dielectric nearer the earth has been gradually increased, so that the discharge path will be inductively prepared; and impulsive-rush discharges, where the strain arises so suddenly that no time is permitted for a prearranged path.

Lightning flashes not instantaneous.

Lightning flashes are by no means as simple a matter as many are apt to believe. In the first place, although of very short duration, they are, nevertheless, not instantaneous, but persist for some small fraction of a second, possibly something in the neighborhood of $\frac{1}{100,000}$ of a second or thereabout. The belief as to the instantaneousness of the flash has, probably, arisen from the fact that, if a disk of cardboard, whose surface is covered with

alternations of white and black sectors, be rotated so rapidly that the eye is unable to detect any differences in the coloration, the entire surface appearing of a uniform gray tint, such a disk, when illumined by a lightning flash, will show its true colors, and will appear to be standing still, no matter how rapidly it has been rotating. This does not, however, prove that the flash is instantaneous, but only that its duration is exceedingly small when compared with the rate at which the disk is turning. In the next place, people are apt to deceive themselves as to their ability to determine the direction in which a lightning flash is passing. It appears to them that they can, at times, see the flash start from the clouds to the earth, and that, at other times, they can see it rise from the earth and discharge into a neighboring cloud. In point of fact, this is an optical illusion, caused by the unequal sensitiveness of the eye to light received at different portions of the optically sensitive portion of the eye, called the retina. In most lightning flashes the electrical discharge passes a number of times successively between the earth and the sky.

Lightning consists of a number of separate discharges that rapidly alternate or flow in opposite directions.

A lightning flash, like the discharge of a Leyden jar, is oscillatory. It is not all over at one discharge, but consists of a number of exceedingly brief discharges separated from each other by very small intervals of time. These successive discharges move alternately in opposite directions until all the energy of the discharge is dissipated. In the case of the Leyden-jar discharge, these alternations occur at a rate of millions per second. In the case of lightning discharges they are less frequent, and, probably occur at the rate of some 300,000 per second. In both the case of the Leyden-jar discharges and the lightning flashes the discharge con-

Oscillatory nature of lightning flash.

tinues until all the energy has been dissipated, and this can only be done by the discharge overcoming some electric resistance placed in its path. If this conducting path is a good one, the discharge does not take place in a single direction only, but causes an oscillation, or surging of electricity to-and-fro, which continues until the flash has spent all its energy.

Effect of resistance on character of discharge.

As we have already seen, the ability of a conductor, such as an ordinary wire, to carry off an electric charge, increases with the increase in its diameter, or with the area of its cross-section. It would seem, therefore, that the thicker the lightning rod, and the greater the area of its cross-section, the better would be its conducting power, and, consequently, the greater its ability to act properly as a lightning rod. This is undoubtedly true for all steady-strain discharges, but it is not true for impulsive-rush discharges.

Conducting power of lightning rod.

The recent marked increase in the use of alternating electric currents, has resulted from our better knowledge of their peculiarities and the many advantages they possess for every-day work. It is well known that when an electric current starts in a conductor it does not at first pass equally through all parts of its cross-section, but begins at the outside and then gradually passes to the interior. Now, in the case of very rapidly alternating currents, the electricity may change its direction so often that it will not be able to penetrate the mass of the conductor, but will be limited to its outside portions. The question, therefore, arises whether it is better to make the lightning rods of solid conductors or of stranded conductors formed by placing together a number of metallic tapes or ribbons.

Relative advantages of solid lightning conductors, and stranded or taped conductors.

NEW YORK'S ELECTRICAL ELEVATED RAILWAY

The New York "L" and Subway trains are electrically driven, the power being taken from a third rail alongside the track, by brass sliding pieces, called collectors, under each car. One of these collectors is indicated by the arrow

Curiously enough, long before this tendency of alternating discharges to be limited to the outer surfaces of solid conductors was discovered, the same question arose as to the relative merits of solid and stranded lightning rods. The first time, however, it came from the well-known fact that it is the outer surfaces of a conductor that determine the value of the electric charge, and that their solid volume has nothing to do with the case, except, of course, to the extent that it determines the value of the outer surfaces. This early scientific controversy had the great Faraday on one side, and Harris, the well-known electrician, on the other. Faraday claimed that the solid volume of a conductor had everything, and the superficial area nothing, to do with the efficient action of a lightning rod. Harris contended that the surface area of the rod was the only important consideration, and that the solid volume had nothing whatever to do with its action. This controversy waged for a long time without being definitely settled. In the opinion of many, indeed, it is not even yet definitely settled, although it is now generally conceded, by those who have carefully studied the matter, that a stranded lightning conductor possesses great advantages over a solid conductor in all cases where the effects of the impulsive rush lightning discharge are concerned.

Faraday and Harris on solid and stranded or taped lightning rods.

Lodge, whom we have already quoted as a great authority on lightning protection, in discussing the reasons why lightning conductors fail to act under certain circumstances, says:

"We have thus mentioned two causes of obstruction met with by rapidly oscillating currents trying to traverse a metal rod. First, there is the direct inertia-like effect of self-induction (the tendency of an electric discharge to produce other electric dis-

Lodge on the reason for the occasional failure of lightning rods to protect.

charges by induction, either on the same conductor as that in which the inducing charge is taking place, or in neighboring conductors) to be added to the resistance proper; the resulting quantity being called by Mr. Heaviside 'impedance,' to distinguish it from resistance proper. (The impedance of a conductor is the resistance it offers to rapidly alternating discharges. This resistance is due to a combination of the true electric resistance of the conductor and an apparent resistance due to the inductive action produced by the discharge on its own conducting path.) For there is a very clear distinction between them: resistance proper dissipates the energy of a current into heat, according to Joule's law; impedance obstructs the current, but does not dissipate energy. (Joule's law refers to the fact that the quantity of heat produced by an electric discharge is proportional to the electric resistance of the conductor through which the discharge is passing, multiplied by the square of the current's strength.) Impedance causes tendency to side-flash, resistance causes a conductor to heat and perhaps to melt. The greater the resistance of a conductor, the more quickly will the energy of a discharge be dissipated, its oscillations being rapidly damped; the greater the impedance of a conductor, the less able is it to carry off a flash, and neighboring semi-conductors are accordingly exposed to the more danger. Resistance is analogous to friction in machinery; impedance is analogous to freely suspended massive obstruction, in addition to whatever friction there may be. To slowly changing forces friction is practically the sole obstruction; to rapidly alternating forces inertia may constitute by far the greater part of the total obstruction: so much the greater part that friction need hardly matter."

Distinction between electric resistance and impedance.

Conditions under which resistance and impedance are governing factors.

In the above quotation Lodge refers to the effect of impedance in producing a tendency of the discharge to "side-flash," that is, to take some other path than that offered by the conductor. This tendency to side-flash occurs in paths whose ordinary electric resistance is enormously higher than that offered by the conductor. It can be shown that in conductors having the form of strands, tapes, or ribbons, the tendency to side-flash is much less than in the case of solid conductors. This is owing to the extended surface which stranded conductors offer to discharges endeavoring to suddenly enter them from the outside.

Phenomena of "side-flash" in lightning discharges.

The tendency of lightning rods to side-flash when impulsive discharges are passing through them, a tendency which has only been known to exist since a comparatively recent date, has rendered it necessary to modify some of the ideas and practices concerning lightning rods that have existed since the time of Franklin up to a comparatively recent date, say 1888. These differences we have condensed from a reprint in the "Electrical Engineer" of a sketch by Lodge as to a public discussion on the subject of lightning-rod protection that took place at the meeting of the British Association in Bath in 1888. Our space necessitates considerable condensation.

Necessity for modifying some old ideas on lightning-rod protection.

(1.) It is not true that properly constructed lightning rods never fail to protect the buildings on which they are placed. They do fail at times, even when the earth is good and the rod is properly erected, because they offer an impedance or resistance to impulsive discharges much greater than is generally believed.

Lightning rods do fail at times.

Oscillatory nature of Leyden-jar discharges.

(2.) Leyden-jar discharges are oscillatory in character. The jar is like a bent spring. Its discharge alternates or moves to-and-fro in the same way, and to a great extent for the same reason that the spring vibrates when bent and suddenly released.

Some lightning flashes oscillatory.

(3.) Lightning flashes, like Leyden-jar discharges, may be oscillatory, but if the resistance met with in the path of the discharge is sufficiently great, the discharge may cease to be oscillatory, and take the form of a steady drain or leak, a form which the old construction of lightning rods are capable of taking care of; but some discharges are impulsive, and these are oscillatory and dangerous.

Resistance often of less importance than impedance.

(4.) Although conductivity in a lightning rod is necessary, yet it is of far less consequence than might be expected. An oscillatory discharge sets up an impedance that results in a very much greater opposition to its discharge than is caused by any ordinary electric resistance. A good and deep earth is advisable, however, so as to protect the gas and water mains.

Care necessary as to how conductors are connected with lightning rods.

(5.) The obstruction to the discharge may be so great that side-flashing may occur at any time. Therefore, the neighborhood of lightning conductors is dangerous during storms, and great care should be taken as to what conductors are purposely or accidentally brought near or into contact with a lightning rod. When a building is struck electric surgings occur in the neighborhood, so that every piece of metal is liable to give off sparks that may ignite gas jets, and so cause fires.

(6.) A stranded conductor, composed of a number of separate pieces of ribbon or tape, is better than

a solid conductor. Each of the separate strands, however, should be thick enough not to be melted by the discharge, since, otherwise, much damage may occur.

Stranded conductors better than solid conductors.

(7.) Points are valuable in serving to permit convective discharges to neutralize the discharge of the clouds. Circumstances, however, may arise when points are of no avail, as in the case of impulsive rushes.

Points generally valuable.

Fig. 64.—Chimney Struck by Lightning Stroke. Note the fact that the upper portion has received nearly all the destructive energy of the stroke, thus indicating its sudden action.

(8.) The ordinary tests of lightning rods by small voltaic batteries, so as to show that the electric resistance is complete, possess but little value.

Tests for electric resistance generally valueless.

(9.) Properly speaking, lightning rods can be said to afford no definitely limited area of protection, since, at times, such violent electric surgings may

No definite area of protection afforded by rod.

occur as to cause damage within areas that the rod is generally able to protect.

The damages produced by lightning strokes arise generally either from the explosive or heating effects. The explosive effects have already been referred to in discussing the mechanical effects produced by disruptive electric discharges. Lightning discharges often shatter large trees in a very remarkable manner. Cases are on record in which large oak trees have been shattered at a certain portion of the tree only, the entire force of the flash appearing to have been expended in quite a limited area. In other cases the entire tree is broken into fragments.

The effects produced by a discharge which struck a tall chimney in Germany are shown in Fig. 64. Here again the explosive effects were local in character, being for the greater part limited to the top of the chimney.

Explanation as to cause of thunder.

The thunder accompanying lightning flashes is generally explained as due to the sudden expansion of the air through the heating effects of the discharge, and the subsequent rushing of the surrounding air into the partial vacuum thus produced. The extent of this vacuum is, probably, increased by the sudden formation of clouds of highly expanded steam or vapor, produced by the vaporization of rain drops through which the discharge passes; or possibly from the atomic decomposition of matter. Since lightning flashes are sometimes several miles in length, the sounds produced at different portions of the path of the discharge, reaching the observer at different times, together with the reflection of these sounds from distant clouds, produce the rattling and rolling sound so characteristic of thunder.

The thunder crash instantly follows the lightning flash. If the discharge occurs at a distance from an observer, the interval between his seeing the flash and hearing the thunder will afford a ready means for estimating how far from him the flash occurred; for, since sound travels through air at ordinary temperatures at about the rate of 1,115 feet in each second, it is only necessary to multiply 1,115 by the number of seconds which elapse between seeing the flash and hearing the sound in order to determine the distance of the flash in feet. It must be acknowledged that the explanations generally given both as to the cause of the thunder, which instantly follows the lightning flashes, as well as the manner in which lightning discharges produce their mechanical effects, are far from satisfactory. Although the sudden expansion of vapor in the mass of the non-conductor, or partial conductor, is, perhaps, the correct explanation, it would seem by no means clear as to what is the exact nature or composition of this vapor.

How distance of place struck by lightning flash may be estimated.

Insufficiency of common explanation as to cause of destructive effects, etc.

There are many cases on record where the amount of energy liberated by a lightning stroke is so great, and the suddenness with which it produces its destructive effects so marked, that the explosive expansion of the vapor of water, or, indeed, of the vapor of any ordinary form of matter, with which we are acquainted, appears to be insufficient to account either for the violence of the effects, or for the limited area in which such effects occur. It would seem that the presence of some entirely different form of matter, other than any with which we are familiar, is necessary. We venture to express the opinion that such a form of matter might be found in a mass of fragmental atomic matter, such as we have alluded to in connection with the possible explanation of

Possible sudden liberation of energy on recombination of fragmental atomic matter.

globular lightning. According to this hypothesis, the lightning stroke suddenly expends a considerable proportion of its energy in disassociating a small quantity of ordinary atomic matter. There is thus formed a small mass of highly heated vaporized matter, the potential energy of which must necessarily be very great. This matter is prevented from again immediately re-combining, both by reason of its high temperature, and also, possibly, by the presence of a peculiar electric charge. When, however, both by loss of temperature, and the dissipation of the charge, the matter is permitted suddenly to recombine into ordinary matter, the liberation in a limited space of an enormous amount of energy would appear to be sufficient to account for the phenomena.

If you live to hear the thunder-peal, don't worry.

Some people are peculiarly sensitive to lightning flashes, and suffer no little from mental depression during their occurrence. This suffering, due to a highly sensitive nervous system, is real, and, to a certain extent, is practically beyond their control. It will be well for such people, and, indeed, every one, to remember that lightning flashes are immediately followed by the peal of thunder, the interval which frequently exists between the two occurrences being due to the great distance of the place struck. If, therefore, one lives to hear the thunder, no danger can possibly come from such a flash, since it is all over by the time the thunder is heard.

Death by lightning instantaneous.

Death by lightning flash is generally instantaneous. Numerous instances are on record where people have been killed so instantaneously that their bodies continued to occupy the exact positions they had in life, so that people passing believed them to be still alive.

It has been remarked that in cases of death by lightning stroke a putrefaction of the body takes place much more rapidly than in cases of ordinary death.

Rapid decay in case of death by lightning.

In many cases of lightning stroke death is only apparent. In all such cases, and even though the person struck appears to be dead beyond any reasonable doubt, yet he or she should be given the benefit of the doubt, and an intelligent endeavor made to restore consciousness. In very many cases the existence of death is apparently so complete as to deceive even experienced physicians; therefore, every effort should be made and persisted in for at least an hour's time, to stimulate both the breathing and the circulation of the blood. While making these efforts the body of the patient should be kept warm by hot flannels, hot water, hot stones, or warm clothing taken from the bodies of surrounding people. Persistent efforts should be made to force the blood from the lower extremities to the heart and head by rubbing the limbs upward. At the same time, while doing this, if possible, do not fail to send for a physician.

Death by lightning strokes often only apparent.

Directions for resuscitation in cases of apparent death from lightning.

It is sometimes noticed, in the case of lightning strokes, that branched markings are found on the surface of the body. These have often been mistaken for photographs of trees, etc. They are merely due to over-filled blood vessels, connected with the capillary system, near the surface of the skin.

Markings on body by strokes.

When a lightning flash strikes a sandy soil it fuses or melts it to glass in its path. The melted glass, subsequently solidifying, marks the path or the track of the discharge in the shape of a branched tube of solidified material. Such tubes are called fulgurites,

Fulgurites, or lightning tubes.

or lightning tubes. An example of such a tube is shown in Fig. 65.

Mechanical effects produced by lightning strokes.

All the effects produced by disruptive electric discharges are, of course, produced by lightning flashes. The mechanical effects are especially noticeable in the tearing and breaking of partially conducting

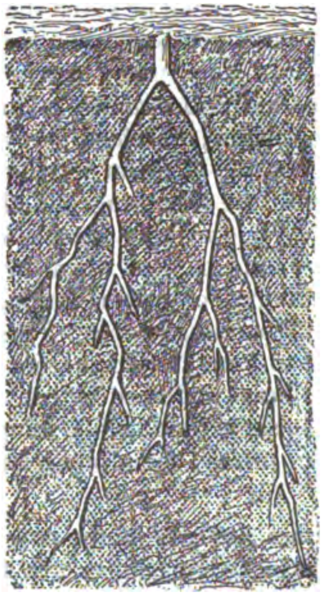


FIG. 65.—Fulgurite or Lightning Tube. Note the branching shape of the discharge, as seen in the specimen of glass thus made by nature.

substances into fragments, but at times exceedingly heavy objects are thrown into the air for considerable distances.

Chemical effects.

The chemical effects produced by the passage of the flash through the air are noticed either in the production of ozone, or in the formation of nitric acid.

The magnetic effects produced by the lightning discharge are seen not only in the demagnetization of compass needles, or in the change or reversal of their polarity, but also in an equally serious effect resulting from the magnetization of parts of the chronometers, or accurate timepieces employed by navigators. This magnetization produces acceleration or retardation of the balance wheel, thus making the clock go faster or slower. There may thus result dangerous errors in the determination of the longitude of the ship. Magnetic effects.

The luminous effects of the discharge are seen in the light of the flash, which is generally of a bright white color, due to the intense incandescence of the air by the heat of the discharge. At times the color of the lightning flash is a violet or bluish purple, due, most probably, to the passage of the discharge through rare air. On rare occasions lightning strokes of a green color have been seen. Luminous effects.

The physiological effects are seen in the convulsive muscular movements of living or even of recently killed animals, or in their permanent injury or death. Physiological effects.

The heating effects are seen in the ignition of inflammable materials, so common during lightning flashes, as well as by the volatilization of metallic bodies. Heating effects.

Since a charged cloud approaching the earth will discharge itself in a lightning flash, as soon as it has produced, by induction in neighboring bodies on the earth, a sufficiently powerful opposite charge to break down or pierce the intervening dielectric, it is clear that tall objects on the earth are more apt to be struck Liability of tall objects to lightning strokes.

by lightning flashes than objects situated directly on the surface. A ship at sea, therefore, being by far the tallest object for, probably, many miles around, is exceedingly apt to suffer from lightning, especially in tropical climates where lightning flashes are both frequent and powerful.

Harris and his system of lightning rods for ships.

The credit for devising the proper system of lightning rods for the electrical protection of ships is due to an English electrician named William Snow Harris, who, after nearly twenty-five years of unceasing labor, and in face of the strongest popular opposition, at length succeeded in introducing a proper system of lightning rods into the ships of the English navy. Prior to Harris' time some effort had been made to protect ships by lightning rods, but this had been done so clumsily that the ships so equipped were, probably, worse off than if they had no lightning rods whatever. These early rods were attached to the masts of the vessel, often only to a single mast, and the rod was carefully kept from all masses of metal in the ship, and passed down into the water from the end of the bowsprit.

How Harris placed his lightning rods on ships.

Harris pointed out the necessity for ensuring good electric connection between the masts and the copper sheathing on the bottom of the ship, thus uniting, in one great chain, the conductors on the masts, the metallic bodies in the hold, and the general surface of the sea, so that when a bolt struck a ship so protected it would find comparatively easy access to the water, which in this case constituted the ground or earth. Harris even recommended the connecting of the rods to the metallic covers on the outside of the powder magazines. All these recommendations caused Harris to be regarded as a most dangerous innovator, and the strongest kind of popular efforts

were made against the adoption of his system. However, when, after a long and tedious effort, it was adopted, the fact gradually dawned on the mind of the English people that ships protected by Harris' system of lightning rods were practically never struck by lightning, while others were frequently struck. Public opinion then promptly changed, and Harris was heralded as a great benefactor. So thoroughly were the services of Harris finally appreciated by the English Government that in 1847 he was accorded the honor of knighthood, and is now generally known in science as Sir William Snow Harris.

Knighthood accorded to Harris.

CHAPTER X

SOME OTHER SOURCES OF ELECTRICITY OF HIGH ELECTRO-MOTIVE FORCE

"From a healthy specimen" (of the Silurus Electricus), "exhibited in London, visible sparks were drawn in a darkened room."—SIR JOHN LESLIE

Electric sources of E.M.F.'s.

THERE are a great variety of electrical sources, or means by which electro-motive forces may be produced. No matter how feeble these E.M.F.'s may be, yet they can, by suitable means, be changed or converted into high E.M.F.'s. A description of some of these electric sources will be given further on in this book, when we have more thoroughly discussed the principles upon which their action is based. It will be advantageous here, however, briefly to describe some sources other than rubbed bodies, by means of which high E.M.F.'s may be directly obtained.

Electric charges produced by tearing, crushing, etc.

Nearly all purely mechanical actions are capable of producing electric charges. The mere crushing of a lump of sugar will be attended, in the dark, by flashes of light, that are due to minute electrical charges produced during the actions which attend the tearing, crushing, or separating of the particles of sugar from one another. In the same manner, during cold, dry weather, when the air possesses good insulating powers, if the linen cover of a paper collar be suddenly torn or separated from its paper backing, electrical charges will be produced that can

readily be shown on an ordinary electrometer. Indeed, under favorable conditions, the separate parts may possess charges sufficiently great to attract other bodies toward them. In a similar manner, certain mineral substances possessing the power of cleavage, that is, of breaking or separating more readily in some directions than in others, and thus readily breaking into sheets or laminæ, are sufficiently electrified by the act of so breaking or separating them as to produce minute sparks visible in the dark. An example of this is seen by suddenly cleaving or tearing sheets of mica apart.

Cleavage producing electric charges.

The crystallization and solidification of some substances also result in the production of electric charges; for example, it has often been noticed that when a fused solid solidifies the mass possesses, on cooling, a well-marked electric charge. This may be shown by the following experiment: melt a small quantity of sulphur or brimstone and pour the molten mass into a small glass vessel, larger at the top than at the bottom, so as to render it easy to remove the mass when solidified by cooling. A small wine glass answers well for this purpose. Before the mass is cooled, insert a glass rod into it, so as to serve as an insulating handle. After cooling, the solid mass, if withdrawn from the glass by the insulating handle, will manifest an electric charge.

Electric charges produced by crystallization and solidification of fused or melted solids.

In a similar manner chocolate, in passing from the fused to the solid condition, likewise manifests an electric charge. Sometimes the crystallization of certain solids, such as arsenic acid, is attended by a flash of light, which is, probably, due to electrification.

Luminous flashes caused by crystallization.

The mere contact of unlike metallic substances,

Electric charges produced by contact.

such, for example, as copper and zinc, is capable of producing, as Volta has shown, feeble electric charges; for example: a disk of copper and a disk of zinc, mounted on insulating handles, when brought together in the air, and afterward separated, will be found to be feebly but oppositely charged. These charges are so small that they require the employment of a highly sensitive form of electroscope to detect them. They will be carefully studied under the head of the Voltaic cell, where they properly belong. But, apart from such experiments, it would appear that, even in all cases of the production of electricity by friction, the mere contact of the surfaces has much to do with the production of electrification.

Pressure causing electric charges.

When pressure is added to mere contact of dissimilar surfaces, the manifestation of the electric charge is in many cases still more strongly marked. The mere pressure of a piece of cork against a piece of amber produces a positive electrification in the cork, and negative electrification in the amber. The same effects are produced by pressing cork against a variety of other substances, both conducting and non-conducting, such, for example, as gutta-percha and metallic substances. The mere compression of certain crystalline substances by the warm hand produces electrification. Among such substances may be mentioned topaz, fluorspar, and tourmaline. It is possible that in some of these cases the electrification is produced by a difference of temperature, for we know that differences of temperature will produce electric charges.

Action of pressure and heat.

Electric charges produced by percussion.

The mere percussion of certain bodies against one another often produces opposite charges in them. Such electrifications may be due both to the effective

contact or friction produced by such blows, or they may be due to differences of temperature so produced. In the case of metallic bodies it is quite possible that the charges produced by friction are really due to differences of temperature, and can, therefore, be regarded as thermo-electric charges. Such charges produced by differences of temperature will be studied under the head of thermo-electricity.

Luminous electric effects produced in vacuous mercury tubes.

A class of electrical effects, probably caused by the combination of contact, friction and percussion, is seen when mercury is allowed to fall against the sides of a clean glass tube, in which a fairly high vacuum has been maintained. The charges so produced are sufficiently great to give rise to flashes of light that can be readily seen in a dark room. By causing the mercury to strike against the glass in harder blows, as by violently shaking the tube, the intensity of these luminous effects will be increased. We have already alluded to similar effects produced by Hawkesbee in his early experiments in this same direction. After Hawkesbee's time Cavendish, Davy, and many others, made series of experiments on the production of electric luminosity in this manner. Not only, however, does the electricity produced by the movements or blows of mercury against glass walls in empty spaces produce luminous flashes, but if an electric discharge is passed through the Torricellian vacuum, or empty space above the mercury in a tall barometer tube, a feeble bluish light, characteristic of the passage of the discharge through space containing traces of ordinary atmospheric air, will be produced.

Luminous electric effects produced by discharges through a Torricellian vacuum.

When differences of temperature are produced in certain crystalline bodies, such, for example, as crystals of tourmaline, quartz, or sulphate of qui-

nine, electrical charges are produced at opposite points called its poles. These are shown in the Fig. 66, at A and B. A common ore of zinc silicate has been called electric calamine, on account of its ability to produce these effects. In Fig. 66 is shown a pyro-electric crystal of tourmaline. The pole A will acquire a positive electrification, and the pole B a negative electrification all the time the crystal is growing warmer. While, however, the crystal is growing cooler opposite electrifications are produced. The existence of these charges can be shown by sus-

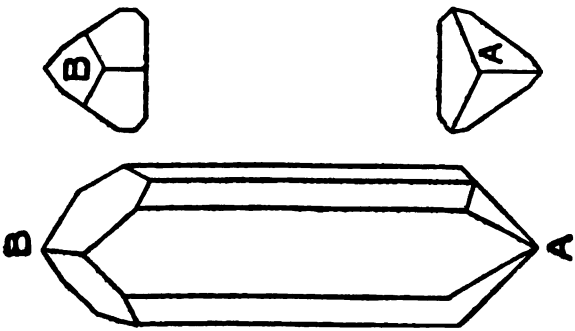


Fig. 66.—Pyro-Electric Crystal of Tourmaline. The pole A, which manifests positive electrification while the temperature of the crystal is rising, is called the analogous pole. The pole B, which acquires a negative charge while the temperature of the crystal is rising, is called the antilagous pole.

pending a heated crystal by a fibre of silk, when the crystal will be attracted or repelled by the approach of another electrified crystal.

The torpedo. A curious electrical source capable of producing high electro-motive forces is to be found in a certain class of fishes. The ancients were aware of the wonderful power of the torpedo, one of these fishes, to produce a benumbing sensation or torpor. They, therefore, called the animal the torpedo, the be-

number. They were, however, unacquainted with the cause of the sensations thus produced.

The torpedo, or the *raia torpedo,* as it is called by scientific men, is found both in the Mediterranean and North Seas. It is a species of flatfish, the general appearance of which is seen in Fig. 67. Here a portion of the skin has been removed at B, to expose the electric organs shown at A. A corresponding set of organs exist on the right hand side of the fish as well as on the left. Each

Description of the *raia torpedo.*

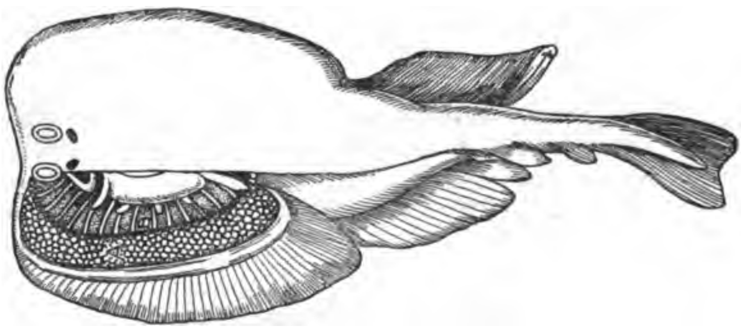


FIG. 67.—The Electric Torpedo, or the *Raia Torpedo*, a species of flat fish found in the Mediterranean and the North Seas.

electric organ is about five inches long and three inches broad, and consists of numerous six-sided, or five-sided, perpendicular columns, that extend from the upper to the lower surface of the body. The torpedo will only give electrical shocks when it is irritated, but when so excited can give a long series of shocks, which follow one another with great rapidity.

The gymnotus, or electric eel, is found in the warmer waters of America and Africa. As seen in Fig. 68, its body is free from scales, and both in its

The gymnotus, or electric eel.

shape and general appearance it bears a great resemblance to the ordinary eel. The position of the electric organs is shown in Fig. 69, in which the animal is partly dissected, so as to expose these organs at *h h*. They consist of flat partitions and thin membraneous plates, intersecting these partitions. As in the preceding case, the electrical charges are under the will power of the animal.

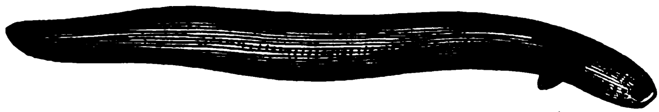


FIG. 68.—The Electric Eel, or Gymnotus. Note its resemblance to the common eel of the United States.

Faraday's experiments with discharges of electric eel.

Faraday made careful investigations on the electric eel. He showed that when one hand is placed on the head and the other near the tail, a shock is felt very similar to that produced by a large Leyden-jar battery when not very highly charged. He also showed, by a series of experiments, such as charging a Leyden-jar battery, producing chemical decompositions and magnetic effects, that the electric charges obtained from this animal are entirely similar to those produced by ordinary electrical machines.

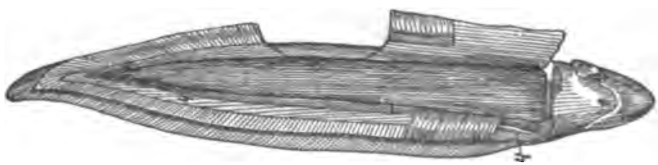


FIG. 69.—Electric Eel, dissected so as to expose electric organs of the animal.

Another species of electric fish, called the *silurus electricus*, is found in the African waters of the Senegal, the Niger and the Nile.

It can be shown that during the life of animals electric charges and currents are produced. These will be studied under the head of animal electricity. In a similar manner during the life of plants electric charges and currents are also produced. **Animal and plant electricity.**

CHAPTER XI

ULTRA-GASEOUS OR RADIANT MATTER

"In these highly exhausted vessels the molecules of the gaseous residue are able to dart across the tube with comparatively few collisions, and, radiating from the pole with enormous velocity, they assume properties so novel and so characteristic as to certainly justify the application of the term borrowed from Faraday, that of radiant matter."—*Lecture to British Association:* WM. CROOKES. Sheffield, 1879.

IN 1861, Prof. William Crookes, a noted English chemist, discovered a new metallic element named thallium. Some time afterward, while weighing a specimen of this element, he had placed his delicate chemical balance in a vacuous space, in order to avoid errors arising from movements of the atmosphere, and thus ensure exceedingly accurate results. He had obtained an exact balance, between the two scale pans, when a beam of sunlight chanced to fall on one of the pans. He was greatly surprised to note that, immediately, the pan on which the sunlight had fallen moved downward, as though the patch of light had added sensibly to its weight. Knowing full well, as a scientific man, that sunlight is imponderable, or possesses no weight, Crookes made a thorough investigation of this phenomenon, the results of which were to add to the three different states or conditions in which matter was then believed to exist; viz., solids, liquids, and gases, a fourth state, for which he proposed the name the ultra-gaseous, or radiant state of matter. The word ultra-gaseous signifies a state or condition be-

Crookes and his discovery of thallium.

Ultra-gaseous or radiant matter.

yond the gaseous state; that is, a variety of the gaseous condition in which the degree of attenuation or rarefaction greatly exceeds that of its ordinary state.

If a glass vessel containing air or gas is subjected to the action of an air pump, as the inclosed space becomes gradually exhausted of its contained air by its removal from the vessel, the amount of air left in the vessel of course becomes less and less, and the number of its molecules, *i.e.*, the exceedingly small particles of matter that are composed of definite groups or combinations of still smaller particles of matter called atoms, left in the vessel, become smaller and smaller.

Effect of vacua on the distance the molecules of a residual atmosphere can move freely.

If, for example, the vessel be exhausted, to say the $\frac{1}{1000000}$ of the density it had at ordinary atmospheric pressures, there will be left in the vessel but one molecule in the space where there were formerly one million molecules. Now we know that in all matter the molecules are in constant to-and-fro motions. In gases, at ordinary pressures, the molecules are unable to move to-and-fro through but very small distances before they strike or jostle against neighboring molecules, which are also moving rapidly to-and-fro. When, however, the gas is rarefied, and there are fewer molecules in the space, the distance through which any molecule can move, without striking against a neighboring molecule, increases. In the case of a gas rarefied to the $\frac{1}{1000000}$ of an atmosphere, since there are one million fewer molecules in the given space, the path or distance any molecule can move through, without striking a neighboring molecule, must be one million times greater than in the same air or gas at ordinary atmospheric pressures.

Mean-free molecular paths.

In other words, the effect of greatly rarefying a gas is to increase the distance its molecules can move

through without striking neighboring molecules. This distance is called in science the mean-free path of the molecule.

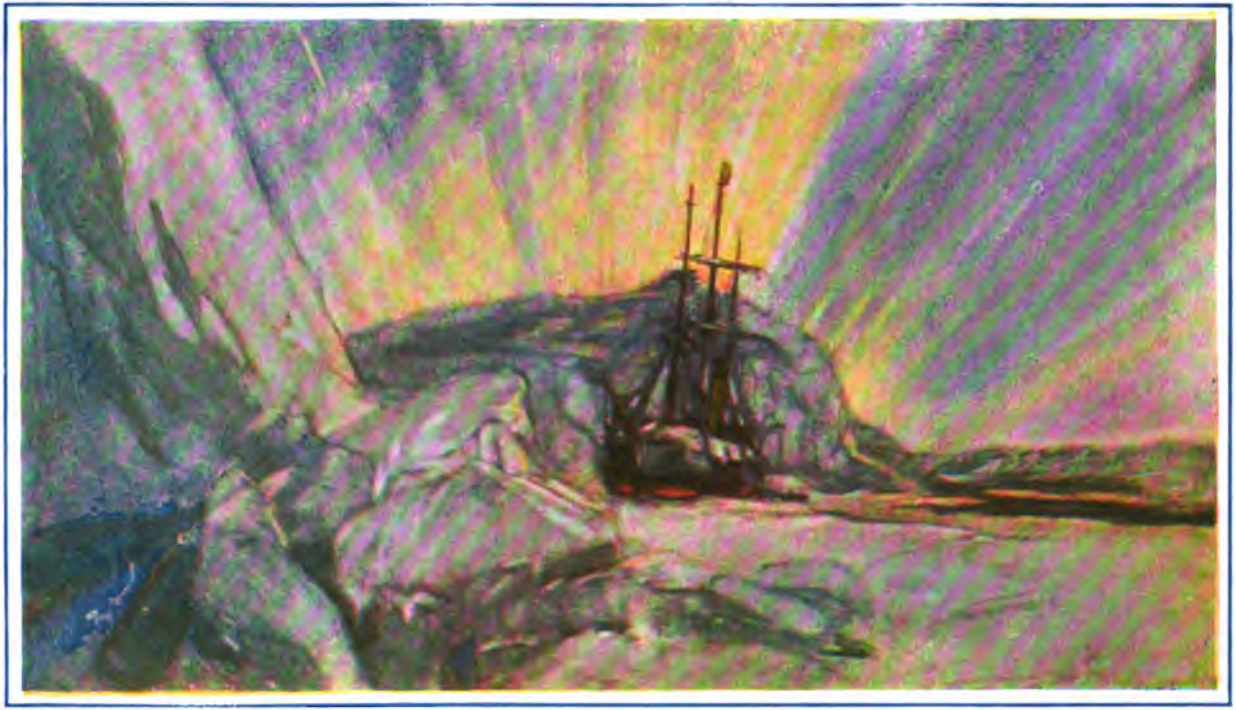
Now, Crookes discovered that if a vessel containing air or gas was exhausted until the number of its contained molecules was so small that they could move in straight lines across the vessel without striking against one another, the ultra-gaseous matter, which fills such a vessel, will possess properties quite distinct from those of ordinary gaseous matter, and that, moreover, these properties are quite capable of explaining the curious action before alluded to, when the beam of sunlight falling on one of the scale pans of the delicate chemical balance placed in a high vacuum caused it to appear heavier than the other pan. As the result of this discovery, Crookes invented an instrument called the radiometer.

Properties of ultra-gaseous matter.

Fig. 70 shows a form of Crookes radiometer. This instrument consists of an easily rotated wheel, provided with arms or vanes, and placed inside a glass globe, whose residual atmosphere is in the ultra-gaseous condition. In order to ensure the ready rotation of the wheel it is delicately supported on needle pivots. The vanes, or arms, are formed of some light material, such as thin sheets of mica, each of which is silvered on one face, so as to readily throw off the light, and is covered with lampblack on the opposite face, to rapidly absorb the light, and thus become warm.

Crookes radiometer.

When a radiometer is exposed to sunlight, or to the light from a burning match or candle, it will be set into a rapid rotation, in which the blackened surfaces or faces of the wheel move away from the direction in which the light strikes them. It is not



THE ELECTRO-MAGNETIC PHENOMENA OF THE AURORA BOREALIS

difficult to understand just why this motion takes place. When light falls on the vanes of the radiometer the blackened surfaces become warmer than the silvered surfaces; consequently, the molecules of residual gas that touch either of these surfaces are thrown off from them, but those which touch the blackened or warmer surfaces, are thrown off with much greater violence than those which touch the silvered surfaces. The kick or reaction that is

Why light falling on a radiometer sets it in rapid rotation.

FIG. 70.—Crookes Radiometer. The light, movable wheel, being surrounded by ultra-gaseous or radiaut matter, is set in rapid rotation when placed in the light.

produced against the blackened surface causes the wheel to rotate in a direction opposite to that in which the molecules fly off. This reaction is similar to that which causes the well-known rotary lawn-sprinkler to turn in a direction opposite to that in which the jets of water are escaping from it.

Now this is just what happened to the delicate balance that Crookes had in the empty space. The beam of the balance on which the sunlight fell was warmer than the other beam; consequently, the mole-

cules of the residual gas were thrown from its surface mainly upward, and this caused the illumined pan to move downward, as if it were heavier than the other. Crookes found that, in order to obtain good results in the vessels he employed for his radiometer, a degree of exhaustion up to as high as the one-millionth of an atmosphere was necessary.

Explanation of the apparent increase in the weight of the scale pan in a vacuum.

Active movements of the molecules of the residual gas are more readily obtained by electric dis-

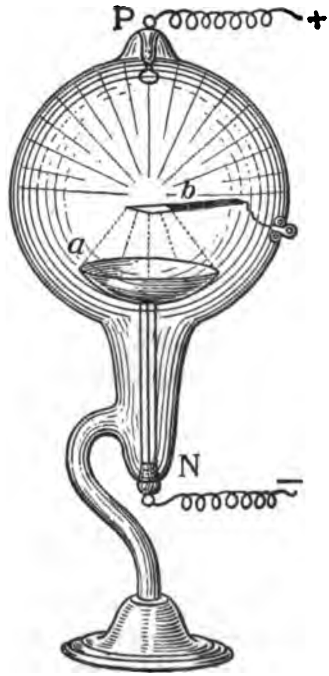


FIG. 71.—Platinum heated to high incandescence by focused molecular stream in ultra-gaseous atmosphere.

charges than by the action of light. When a Crookes tube, that is, a glass tube containing its residual gas in the ultra-gaseous radiant state, is provided with

leading-in wires terminating in suitably shaped metallic plates called electrodes, is traversed by electric discharges, a stream of molecules is thrown violently from the plate or metallic surface connected with the negative terminal of the battery; or, as it is more generally called, from the cathode or negative electrode. A number of very beautiful and interesting luminous effects are produced by the bombardment of different substances by the molecules thus thrown off from the cathode. If, for example, the cathode N is furnished with a concave mirror *a*, Fig. 71, the molecular stream is brought to a single point or focus, just as light would be from a similarly shaped mirror, or as a beam of light is brought to the focus of a burning glass. If this stream is directed against a piece of platinum *b*, placed at the focus, it will raise the temperature of the platinum sufficiently high to melt it.

Molecular stream produced in Crookes tubes by electric discharges.

Incandescence produced by molecular bombardment.

In the ultra-gaseous atmosphere of a Crookes tube, the passage of an electric discharge causes a stream of the residual gas to move off at right angles from the surface of the cathode, and this independently of how the metallic plate connected to the positive electrode, or, as it is called, the anode, is situated. In this respect a Crookes tube differs markedly from an ordinary vacuum, where the luminous discharge always passes between the anode and the cathode. In Fig. 71A are shown two tubes, each of which is furnished with one cathode and three anodes. The one at the right has its residual gas in the shape of ultra-gaseous matter, and the one to the left that of an ordinary vacuum. When an electric discharge is passed through these tubes, the Crookes tube, the tube on the right-hand side of the figure, whose cathode is furnished with a concave metallic mirror, has the streams of residual

Difference in molecular stream paths in partial and in high vacua.

gas thrown off from the surface of the cathode in straight lines, collecting at a focus near the centre of the tube, and diverging to the opposite wall of the tube, irrespective of the position of the anode; while in the case of the tube to the left, which contains a partial vacuum, the streams from the cathode diverge in three branches, moving to the three anodes placed as shown.

When phosphorescent substances are placed at the focus of a Crookes tube, whose cathode is provided

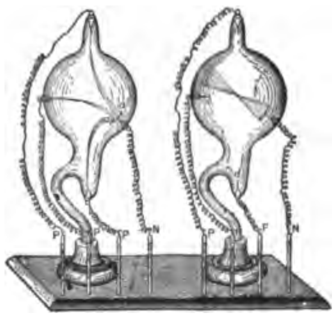


FIG. 71 A.—Effect of degree of vacuum on paths of molecular streams caused by electric discharges.

with a concave mirror, beautiful luminous effects are produced.

Cathode rays. The luminous rays coming from the cathode of a Crookes tube, in which the vacuum is so high that the residual atmosphere is in the ultra-gaseous state, are called the cathode rays. These rays, as we have seen, possess the power of heating refractory substances to a state of high incandescence, and of exciting phosphorescence in certain substances as above described. It was formerly believed that cathode rays consist of molecules of the residual gas. It is now believed, however, that they consist

of particles of matter much smaller than the molecules, even smaller than the atoms. These particles are called corpuscles or electrons, and are believed to consist of exceedingly minute fragments torn from the atoms. They are thrown from the surface of the cathode by some, yet to be explained, action of electricity. These particles move with a speed that has been estimated to be, probably, somewhere near one-twentieth the velocity of light. These corpuscles or electrons carry a negative charge of electricity.

Speed of electrons.

CHAPTER XII

ROENTGEN OR X-RAYS—THE PHOTOGRAPHY OF THE INVISIBLE

"We will draw the curtain and show you the picture."—*Twelfth Night,* Act I, Scene 5.

ROENTGEN, of Würzburg, Bavaria, while engaged, in 1895, in a study of the cathode rays, had so thoroughly covered the Crookes tube, with which he was experimenting, with black cardboard, that none of the light it emitted could pass into the darkened room. Near this tube was a sheet of paper covered with a chemical substance called tungstate of calcium, which possesses the property of fluorescing. Now, during his experiments, Roentgen noticed that something, apparently very much like light, had evidently passed through the blackened cardboard on the Crookes tube, and had excited fluorescence in the substance that covered the paper; for it commenced to emit light. On making a careful investigation of this phenomenon, Roentgen discovered that the action was due to a hitherto unknown radiation invisible to the eye, but capable, as we have seen, of producing luminous effects when allowed to fall on fluorescent substances, and capable also, as he afterward discovered, of passing through substances opaque to ordinary light, and, like light, able also to cause the chemical decompositions necessary for producing photographic effects. Roentgen proposed for these rays the name of X-, or the unknown, rays. They are, however,

Roentgen's discovery of a new form of radiation.

X-rays or the Roentgen rays.

frequently called Roentgen rays, after the name of their discoverer.

The Roentgen rays are not the same as the cathode rays, but appear to be produced by the cathode rays when they strike against a solid object, such, for example, as the walls of the glass tube, or when the cathode rays are focused by means of a mirror, and are so caused to fall on a piece of metal. Roentgen rays, so produced, pass off in all directions from the metallic surfaces.

Roentgen rays not the same as the cathode rays.

It may be interesting to note, in this place, a brief extract from a description given by Roentgen, in a preliminary communication to the Würzburg Physico-Medical Society, in December, of 1895:

"1. If we pass the discharge from a large Ruhmkorff coil through a Hittorf or a sufficiently exhausted Lenard, Crookes, or similar apparatus, and cover the tube with a somewhat closely fitting mantle of thin black cardboard, we observe, in a completely darkened room, that a paper screen washed with barium-platino-cyanide lights up brilliantly, and fluoresces equally well whether the treated side or the other be turned toward the discharge tube. Fluorescence is still observable two metres away from the apparatus. It is easy to convince one's self that the cause of the fluorescence is the discharge apparatus and nothing else.

Effect of X-rays on barium-platino-cyanide.

"2. The most striking feature of this phenomenon is that an influence capable of exciting brilliant fluorescence is able to pass through the black cardboard cover, which transmits none of the ultra-violet rays of the sun or of the electric arc, and one immediately inquires whether other bodies possess this property. It is soon discovered that all bodies are transparent to this influence, but in very different

Transparency of many substances to X-rays that are opaque to ordinary light.

degrees. A few examples will suffice. Paper is very transparent; the fluorescent screen held behind a bound volume of 1,000 pages still lighted up brilliantly; the printers' ink offered no perceptible obstacle. Fluorescence was also noted behind two packs of cards; a few cards held between apparatus and screen made no perceptible difference. A single sheet of tin-foil is scarcely noticeable; only after several layers have been laid on top of each other is a shadow clearly visible on the screen. Thick blocks of wood are also transparent; fir planks from 2 cm. to 3 cm. thick are but very slightly opaque. A film of aluminium about 15 mm. thick weakens the effects very considerably, though it does not entirely destroy the fluorescence. Several centimeters of vulcanized India-rubber let the rays through. (For brevity's sake I should like to use the expression 'rays,' and to distinguish these from other rays I will call them 'X-rays.') Glass plates of the same thickness behave in a different way according as they contain lead (flint glass) or not; the former are much less transparent than the latter. If the hand is held between the discharge tube and the screen, the dark shadow of the bones is visible within the slightly dark shadow of the hand. Water, bisulphide of carbon, and various other liquids, behave in this respect as if they were very transparent. I was not able to determine whether water was more transparent than air. Behind plates of copper, silver, lead, gold, platinum, fluorescence is still clearly visible, but only when the plates are not too thick. Platinum 0.2 mm. thick is transparent; silver and copper sheets may be decidedly thicker. Lead 1.5 mm. thick is as good as opaque, and was on this account often made use of. A wooden rod of 20 by 20 mm. cross-section, painted white, with lead paint on one side, behaves in a peculiar manner. When it

Opacity of some substances to X-rays.

Possibility of seeing the ordinarily invisible.

is interposed between apparatus and screen it has almost no effect when the X-rays go through the rod parallel to the painted side, but it throws a dark shadow if the rays have to traverse the paint. Very similar to the metals themselves are their salts, whether solid or in solution."

It may be well here to call attention to a fact observed by Hawkesbee, who, in 1705, apparently came near discovering the X-rays. Hawkesbee was experimenting with the then well-known globular electrical machine. He had, however, replaced the ordinary globe of this machine by a glass globe coated on the inside with sealing-wax, which was at least one-eighth of an inch thick in places, and was, consequently, absolutely opaque. This globe also differed from the globe ordinarily employed by having a vacuum maintained within it. Hawkesbee noticed that when his hand was applied to the outside surface of the globe, so as to act as a rubber, the shape of his hand was distinctly seen in the concave surface of the wax, as if it had become transparent. The same result was obtained if a still more opaque substance, viz., pitch, was used in place of the wax. It would appear that Hawkesbee had thus accidentally produced X-rays, or something very much like them, in these experiments. A repetition of Hawkesbee's experiments, under more favorable conditions, might yield valuable results to science.

A probability that Hawkesbee unknowingly obtained the X-rays as early as 1705.

Perhaps one of the strangest circumstances attending the discovery of the X-rays is the possibility they afford of permitting us to see what would otherwise be invisible. This possibility arises from two characteristic properties of these rays; viz., their ability to pass through substances opaque to ordinary light, and their ability, though invisible to

the eye, of causing such parts of surfaces as are covered with fluorescent substances on which they fall to emit light, and thus become visible to the eye. A surface thus covered with a fluorescent substance was invented by Edison shortly after he began studying the X-rays. His instrument is called a fluoroscope. This instrument, as shown in Fig. 72, consists of a darkened box or chamber, having the general appearance of an ordinary stereoscope, the small end of which is shaped so as to tightly fit the eyes, and the large end fitted with a plate, the inner surface of which is covered with some fluores-

Edison's fluoroscope.

FIG. 72.—Edison's Fluoroscope, employed for examining the interior of the human body by the X-rays.

cent material like the tungstate of calcium already referred to, or the barium-platino-cyanide. When using the fluoroscope, the object to be examined, say the hand of one of the operators, is held outside the fluoroscope, between it and the X-ray tube. Now, the different parts of the hand are unequally transparent to the X-rays. Some parts, like the flesh and blood, allow the rays to readily pass through them, while others, like the bones, are opaque to them. Between these there are different degrees of opacity and transparency; consequently, there will fall on the surface of the fluoroscope different quantities of X-rays, the opaque portions receiving but little of the rays, and the transparent

portions a greater quantity of the rays. It follows, therefore, that the surface of the fluoroscope will emit different degrees of light, and that an observer looking into it will see an image of the opaque body looked at in the shape of more or less distinctly outlined shadows.

Nature of the fluoroscopic picture.

In the same way it is possible for physicians to examine any of the bones of the human body, and,

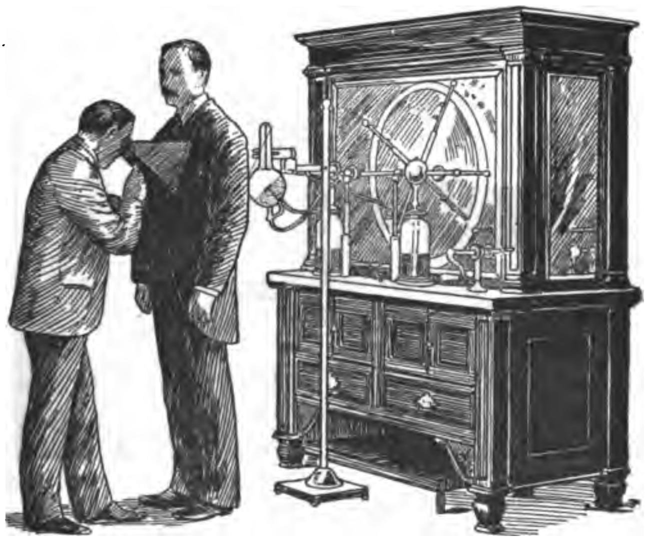


FIG. 73.—Examination of the chest of a patient by the use of the X-rays and an Edison Fluoroscope. Note that only the upper, left-hand half of the X-ray tube is emitting the X-rays.

to a certain extent, many of its internal organs, and thus determine the condition in which these may happen to be. It is not necessary to remove the clothing during this examination, since all the ordinary materials employed for clothing are quite transparent to X-rays. In Fig. 73, the physician is shown as examining the chest of a patient. The X-ray tube is shown as placed at the back of the pa-

tient, and the fluoroscope is applied to the chest by the physician, who is looking into the instrument. Here the electric discharges are obtained from the discharge of a powerful induction or influence machine, whose terminals are connected in the manner shown with the leading-in wires connected with the X-ray tube.

For the photography of the invisible, in addition to the ability of the X-rays to pass through sub-

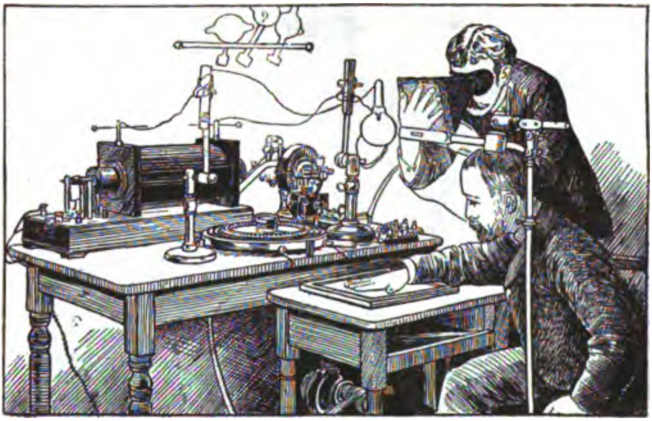


FIG. 74.—Practical Application of X-rays and Fluoroscopic Screen. The Ruhmkorff coil is at the far end of the larger table.

The photography of the invisible.

stances opaque to ordinary light, there must be added their ability to act on photographic plates like ordinary light. In order to take a photograph of some object that is covered by substances opaque to ordinary light, a sensitive photographic plate is covered with several thicknesses of blackened paper, or is placed in the ordinary plate holder, with its sensitive surface toward the source of the X-rays. An object, say one of the hands of an operator, is then placed between the source of the X-rays and the photographic plate. In this instance a hand is rested

directly on the top of the plate. As shown in Fig. 74, the hand is placed on the top of an ordinary plate holder, resting on a table. The X-ray tube, Radiographs of hand and foot.

FIG. 75.—X-ray picture or radiograph of the human hand.

placed before the hand, has its terminals connected, in this case, with a device called the Ruhmkorff coil. Another experimenter is shown in the same figure

FIG. 76.—X-ray picture or radiograph of the human foot.

as examining his hand in a fluoroscopic screen held between the X-ray tube and the outside of the fluoroscope.

Both the fluoroscopic examination and the photographic method afford great aid to surgeons and physicians generally in the examination of the human body; for example, when a person is suffering from the effects of a gunshot wound, the painful exploration of the body, by means of the steel instrument called the probe, is no longer necessary. Now

Location of foreign substances in the human body by the X-rays.

FIG. 77.—X-ray Tube, from device by R. V. Wagner & Co., of Chicago.

a simple fluoroscopic examination, or, what is often still better, a more permanent record by means of an X-ray photograph, radiograph, or skiagraph, as it is generally called, will give at once the location of the ball; for metallic bodies, like lead, are exceedingly opaque to the X-rays, therefore their shadow is well defined either on the fluoroscope screen or in the radiograph.

A radiograph of the human hand is shown in Fig. 75. Here the bones are clearly seen through the transparent flesh and blood vessels with which they are covered. In Fig. 76, a similar radiograph is shown of the foot, the separate bones being clearly outlined in the same manner.

A variety of different forms have been given to X-ray tubes. In the form shown in Fig. 77, a single

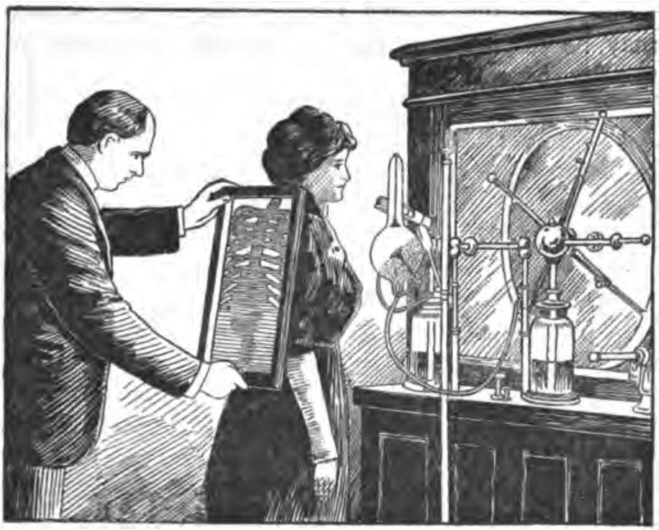


Fig. 78.—Fluoroscopic examination of patient by use of X-rays in connection with a Fluoroscopic Screen.

cathode is provided with a concave metallic mirror. There are two anodes. The anode which receives the cathode rays, and therefore emits the X-rays when the cathode stream falls on its surface, is generally called the anti-cathode, and is placed in the inclined position shown. This anode is made heavy, so as to avoid rapid destruction by means of bombardments from the cathode rays to which it is sub- **The anti-cathode.**

jected. Provision is also made for the expansions and contractions which follow changes in temperature, so that they shall not produce warping and consequent destruction of the tube. When this tube is in proper operation one-half of the surface is lighted with a peculiar greenish light, as shown in Fig. 78, where an image of the spinal column and ribs of a patient standing in front of a tube is clearly seen on the surface of a glass fluorescent screen—held, as shown, back of the patient; for when the room is kept dark a fluoroscopic screen may be employed instead of placing the screen in the fluoroscopic box.

Provision to avoid destruction of the tube.

CHAPTER XIII

RADIO-ACTIVITY—SPLIT ATOMS OR ELECTRONS

"The highest reach of human science is the recognition of human ignorance."—SIR W. HAMILTON.

JOHN DALTON, in a publication entitled "The New System of Chemical Philosophy," published in 1807, stated that the ultimate particles of matter consist of exceedingly minute bodies called atoms. He maintained that these atoms are infinitely hard, so as to be incapable of being cut, scratched or broken. It was for this reason that they were called atoms; the word atom meaning matter which is indivisible, or which can not be cut. Dalton pointed out that, when a chemical combination takes place, it is the atoms that enter into combination with one another; that each atom has a definite relative weight compared with hydrogen taken as unity or one; that the composition of all chemical compounds is definite, and consists of the indivisible parts or atoms entering into combination with each other; that all elementary substances that are capable of entering into combination, combine in definite proportions by weight, this combination taking place between either two, three, or more whole atoms. Dalton believed that when chemical decompositions and subsequent recombinations occurred, an atom of one elementary substance was invariably replaced by a single atom of some other chemical substance. We now know,

Dalton's atomic theory.

Some points in Dalton's atomic theory.

however, that in such cases a single atom may be replaced by two, three, or more atoms of other substances, according to what is called their atomicity or valency.

The position occupied by Dalton's theory for many years, may be seen by a statement made by Dr. Thorpe, in 1849, in his "Essays on Historical Chemistry"; viz., that "every great advance in chemical knowledge, during the last ninety years, finds its interpretation in this [Dalton's] theory."

Lucretius and Anaxagoras on the constitution of matter.

The ancients had somewhat similar ideas concerning the constitution of matter. Lucretius held that matter is made up of indestructible atoms, while Anaxagoras held that matter was not made up of separate parts, but was continuous and infinitely divisible. While scientific men are still somewhat divided in respect to the constitution of matter, some, like Maxwell, holding that it is impossible to regard matter as homogeneous and continuous, and others, like Tait and Kelvin, believing that matter is continuous, compressible, and intensely heterogeneous; still, with some few exceptions, at comparatively recent dates, chemists very generally held to Dalton's views as being at least convenient, and, in point of fact, most chemical theory has been based on such ideas until quite recently.

Maxwell, Tait and Kelvin on the constitution of matter.

Are atoms indivisible?

A feeling, however, has gradually been arising in the minds both of physicists and chemists, that not only the atomic theory, but also some other fundamental physical ideas, such as that of the character of the luminiferous medium through which the waves of light are propagated, need marked modifications.

In a recent address by the President of the British

Association for the Advancement of Science, an admirable discussion is given of some of the above-mentioned changes that scientific men have found necessary to make in the general ideas which have hitherto been held almost universally, and which may properly be called fundamental scientific beliefs. In this address, Prof. A. W. Rücker, the President of the Association, calls attention to the fact that it is impossible to regard such matter as gold, water, or air, as being uniformly continuous throughout. He calls attention to the fact that, in such matter, there is a condition of internal commotion, in which the particles rapidly move to-and-fro.

Rücker on some fundamental scientific beliefs.

In the above address Rücker cites a curious experiment of Sir W. Roberts Austin, in which pieces of gold and lead were placed in contact with each other, and kept in a temperature of about 64° Fahrenheit for four years. At the end of this period particles of the gold had travelled into the lead to such an extent that not only were the two metals united, but "on analysis appreciable quantities of the gold were detected even at a distance of more than 5 mm. from the common surface, while within a distance of three-fourths of a mm. from the surface gold had penetrated into the lead 1 oz. 6 pwts. per ton, an amount which could have been profitably extracted." Such effects, he properly states, could not possibly be explained but on the supposition of separate parts, in a state of motion, having penetrated into the spaces between the corresponding parts of the superposed body. He calls attention to the fact that the phenomena both of expansion and heat, as well as the above phenomenon of combination of the lead and gold, could not be made intelligible by any other hypotheses than those which are at the basis of the atomic theory.

Diffusion of gold into lead at ordinary temperatures.

Coarse-grainedness of ordinary matter.

The conclusion is reached that matter possesses relatively a coarse-grainedness; is not identical in constitution throughout; and that adjacent minute parts are distinguishable from each other, either by being of different nature or in different states.

Ionization of gas.

When a current of electricity is made to flow through a gas, some of the atoms of the gas appear to be torn or divided into parts which carry positive and negative charges, as they move in opposite directions. It is only when such a breakdown occurs that the gas is able to conduct electricity. By the passage of the X-rays through a gas, therefore, it appears that some of the atoms of the gas are broken into fragments by the radiation, and that these broken parts are oppositely charged, and scattered among the unbroken atoms. A gas so acted on is said to be ionized. Here, then, we have reached a point where the so-called atom has fragments broken off from it, an idea which is very different from the idea so long held by most chemists and physicists that atoms could not be cut or broken.

Atomic chips produced by X-rays.

Prof. J. J. Thomson believes that it is possible thus to break off from an atom a small part of its mass, a quantity not exceeding $\frac{1}{1000}$ of the whole. He has called these fragments of the atom the corpuscles. He believes that these corpuscles act as the carriers of a negative charge in an electric current. He believes that it is quite possible, nay, even probable, that the atoms of elementary substances are composed of combinations of parts of some simpler fundamental form of matter—possibly, as has been suggested by some, of the universal ether. If such views be correct, it may be possible to realize the dream of the alchemist, and to convert or change any of the baser metals into gold.

Transmutation of baser metals not necessarily impossible.

In 1896, a Frenchman named Henri Becquerel, while studying the action of the X-rays on certain phosphorescent substances, in causing them to emit a radiation, which, like the X-rays, possessed the power of passing through substances opaque to ordinary light, noticed the curious fact that in the case of uranium salts, previous exposure to sunlight was unnecessary. In other words, Becquerel discovered that salts of uranium are able to give off radiation at all times, without any exposure to sunlight, and that such radiations, like the X-rays, can pass through opaque bodies and affect sensitive photographic plates. These rays are called uranium rays; or, from the name of their discoverer, Becquerel rays. They possess the power of discharging electrified bodies in their neighborhood by the ionization of the air surrounding them. In this respect they are like the X-rays and the cathode rays. Becquerel or uranium rays.

Several months after this discovery by Becquerel, two investigators discovered that thorium and its compounds possess, like uranium, the ability to emit peculiar rays. Subsequently, through a careful study of a mineral called pitchblende, which is one of the principal ores from which uranium is obtained, there were discovered two hitherto unknown elementary substances, which are at least one hundred thousand times more sensitive than uranium, and possess a radio-activity, as this peculiar property is called, one hundred thousand times as great as that of uranium. These substances were called polonium and radium. A third additional substance was subsequently discovered, called actinium, which also possessed marked powers of radio-activity. Discovery of new elements, polonium, radium and actinium.

The peculiar rays emitted by these substances are called respectively polonium rays, actinium rays, and

Polonium, actinium and radium rays.

radium rays. Polonium rays appear to be readily stopped by a very thin sheet of metallic foil. Uranium rays are more penetrating, passing through metals, glass, and, in fact, all substances, with, however, a greater or less loss in intensity. Polonium, radium, and actinium rays appear to consist of mixtures of both penetrating and non-penetrating rays.

X-ray burns.

Like the X-rays, the radium rays possess the power of reddening or burning the skin, and may cause severe inflammation, only in the case of the radium rays the influence does not set in until three or four weeks after the exposure. The curious fact, therefore, exists that a fragment of radium, which continues to emit rays whether exposed to sunlight or not, if carried in a small glass bottle in one's pocket, would be able to produce a serious burn without his knowing it until three or four weeks afterward, unless he had taken the precaution of shielding himself against its malign influence by surrounding the bottle with an impenetrable covering of thick lead.

Curious effect of radium ray burns.

Secondary X-ray and other radiation.

But we are not yet through with the curious category of these peculiar rays. If the X-rays are permitted to strike against some object, they are able, like the cathode rays, to produce a secondary radiation. The Becquerel rays possess the same property. These secondary rays possess the power of ionizing gas, and affecting photographic plates. It will be impossible, however, for us to give them any further attention.

Kelvin's modification of Franklin's single-fluid electric hypothesis.

The fragmental atomic matter or corpuscles are sometimes called electrons, or electrions. Kelvin has recently proposed a modification of Franklin's single-fluid hypothesis, in which he suggests that the single imponderable electric fluid, which Franklin assumed

to exist in all matter, consists of equal and similar atoms or electrons, much smaller than the atoms of ponderable matter.

Similarity of electronic matter to ordinary gross matter

William Crookes, in a recent paper, states that electrons emanating from radio-active bodies behave in all respects like material particles, and, unlike ether waves, are impeded by the molecules of the surrounding medium. He states that the electrons from actinium partake of the properties of a fog or a mist of material particles. He explains how the electron theory throws light on a fact that has long puzzled scientific men, viz., that if a coin is placed on a sensitive photographic plate in perfect darkness, and connected for a few seconds with one terminal of an induction coil, a development of the plate will show an image of the raised portions of the coin that have come in contact with the sensitized surface. This has generally been ascribed to an electrified stream of air particles, or to the brush discharge escaping from the sharp portions of the coin; but, if the coin be imbedded at the centre of a block of paraffin 2 cm. thick, where it would be impossible for it to emit streams of electrified air, a photograph can still be obtained by means of the induction coil. It would seem, therefore, that the electrons, which pass easily through the paraffin from the coin to the plate, are the real cause of the phenomenon.

Action of electrons in producing photographic images.

II

MAGNETISM

CHAPTER XIV

EARLY HISTORY OF MAGNETISM

"In early times the magnetic power was believed to belong only to the lodestone. It was next believed to belong only to the lodestone and iron or steel; now, however, every material substance is found to be affected more or less by its influence."—WOODCROFT: *English Patents, Abridgments*

Properties of lodestone.

THERE exists in nature a particular ore of iron called the lodestone, some specimens of which naturally possess magnetic powers; viz., that of attracting or drawing to them small pieces of iron, and also, when suspended so as to be able to readily move or turn in any direction, of coming to rest when pointing approximately to the geographical north. This ore of iron occurs in nearly all parts of the world, and is, therefore, by no means rare or difficult to find.

Magnetism known to ancients so far as its curious properties were concerned.

In the form of lodestone, magnetism was known to the ancients at an exceedingly early date, although they were not aware of the cause of its peculiar properties. Which of its two characteristic properties above referred to, *i.e.*, its attractive or directive force, was first observed is not certainly known. In the opinion of some, its power of drawing iron to it was believed to have been first discovered, but according to others, its power of directing or pointing to the north was the property that was first noted.

Those who believe that the attractive power of magnetism was first discovered assert that its discoverer was a shepherd named Magnes, who was very unexpectedly detained on Mt. Ida, in Phrygia, Asia Minor, by the iron nails in his shoes being held fast to a large mass of lodestone, with which they accidentally came into contact. According to others, this detention was caused by the curious fact that he was unable to detach his shepherd's crook from a mass of lodestone, to which it was firmly held by the iron hook with which it was mounted. According to still others, the discovery of the attractive power of the lodestone was made about one thousand years before Christ, by a Greek, who obtained from Magnesia, in Lydia, Asia Minor, a specimen of the lodestone. There are still others who believe that the word magnet was derived from the Latin word "magnis," which means heavy, in reference to the high specific gravity of lodestone.

Magnes astonished on Mount Ida, in Asia Minor.

Alleged discovery of magnetism by a Greek in a lodestone obtained from Magnesia, Asia Minor.

If very early Chinese history is to be credited, it would appear that the world's knowledge of magnetism extended into a period much earlier than the times of the early Greeks or Romans; viz., to a date as early as 2600 B.C. In Duhalde's "General History of China," it is asserted, that, according to ancient records, when the Emperor Hoangti was warring against Tchi Yeou, on the termination of a battle, disastrous to the latter, Hoangti, by the use of a needle, which possessed the power "to determine the four parts of the world," "overtook Tchi Yeou, made him prisoner, and put him to death." In the same history it is stated that at a later date, 1040 B.C., another Chinese notable, named Tchieou Kong, gave to certain ambassadors a valuable present in the shape of an instrument, which possessed the strange power of guiding them home. One side

Knowledge of magnetism credited to the Chinese 2600 B.C.

Magnetism said to have been known to Tchieou Kong, 1040 B.C.

of this instrument is said to have pointed to the north, and the other side to the south.

Whether the early knowledge concerning magnetism in China began with the discovery of the directive power of the magnet, or, with the discovery of its power of attraction for iron, is uncertain. Even if we endeavor to solve this question by etymological study of the early words used for magnet, we will still experience the same uncertainty. Thus, in Chinese, the lodestone is called "thsu-chy," or the lovestone; also "hy-thy-chy," which means the stone that snatches up iron. In fact, in nearly all languages we can find words whose etymology would appear to have been derived from its power of attraction. This has been pointed out by Sir William Snow Harris, in his work on "Rudimentary Magnetism." Thus, in the Siamese language the word for magnet is "me-lek," or that which attracts iron. In Sanscrit the word is "ayaskânta," or loving toward iron. In the Talmud, the "Jewish Traditions of the Elders," a magnet is called "achzhàb'th," or the stone which attracts. Even in the European languages, the French call a magnet "l'aimant," or the loving stone; and in Hungarian it is called "magnet kö," or the lovestone.

Etymological signification of early words for the lodestone referring to its attraction for iron.

On the other hand, the magnet has also been called by words that refer to its ability to point or direct to the geographical north. For example, in Chinese, the magnet is called "tchu-chy," which means the directing stone. In a Chinese dialect (Tonkinin) the word is "d'ànamtchûm," which means the stone which points or shows the way to the south. In Sweden the lodestone is called the seeing stone, or the "segelsten." In Icelandic, it is called the leading stone, or the "leiderstein," and in Saxon, its signifi-

Etymological signification of early words for the lodestone referring to its directive power.

cation is to lead, "laedan," from which we get the name lodestone. In this last connection it might be well to call attention to the fact that the spelling loadstone, sometimes given to this word, and which, probably, signifies heavy stone, is not as much in accord with etymological usage in different parts of the world, as the orthography lodestone.

Before leaving this very interesting early history of magnetism, it may be stated that Homer, one thousand years B.C., gives a brief mention of the directive power of the lodestone. Thâles, the Greek, to whom we have already referred in connection with the rubbed amber, speaks in his writings of the lodestone as if he confidently believed that it was possessed of a variety of animal spirit, and was, therefore, endowed with a kind of life. Woodcroft, in his introduction to the subject of magnetism in the Abridgments of Specifications Relating to Patents for Inventions in Electricity and Magnetism, cites the following additional early writers as calling attention to the directive power of the magnet, viz., Pythagoras, 600 B.C.; Euripides and Plato, 500 B.C.; Aristotle, 400 B.C.; Lucretius and Cicero, 100 B.C. It was the Roman poet, Lucretius, who, in his philosophical work "De Rerum Natura," spoke intelligently concerning the magnet. We append Dr. Busby's translation of this passage:

Homer, 1000 B.C., mentions directive power of lodestone.

Thales' belief in the presence of an animal spirit in the lodestone.

Early knowledge of directive power of lodestone.

"Now, chief of all, the magnet's power I sing,
And from what laws the attractive functions spring:
The magnet's name the observing Grecians drew
From the magnetic region where it grew;
Its viewless potent virtues men surprise,
Its strange effects they view with wondering eyes,
When, without aid of hinges, links, or springs,
A pendent chain we hold of steely rings.
Dropt from the stone—the stone the binding source,—

Busby's translation of ode of Lucretius on the magnet.

Ring cleaves to ring, and owns magnetic force:
Those held superior, those below maintain,
Circle 'neath circle downward draws in vain,
Whilst free in air disports the oscillating chain."

Pliny on the repellent power of the magnet.

In addition to Lucretius, Pliny, who, in the thirty-sixth book of his Natural History, appears to have observed the power possessed by a magnet of repelling bodies, thus remarks: "There is a kind of stone in Ethiopia, which will not abide iron, but repulses and driveth iron away from it." At a much later date, A.D. 400, Marcellus refers to the lodestone, both as attracting and repelling iron. Lucretius, in "De Rerum Natura," mentioned above, speaks thus obscurely concerning the repelling power possessed by a magnet: "I have seen, at Samothrace, iron jump and filings dance in brass vessels, when a piece of lodestone was placed underneath, so that it seemed as if the iron was repelled from the stone." Here, undoubtedly, Lucretius was in error. There was certainly no repulsion, but merely attraction of the magnet drawing the iron particles to it and permitting them to be replaced by others, as its position was changed from one side of the brass vessel to the other.

Lucretius on supposed repulsion of iron filings by a lodestone.

The exact time of the discovery of the mariner's compass, in which the directive power of the magnet is employed to direct a ship in its course across the ocean, is also uncertain. Jamlichus, in his Life of Pythagoras, says "that Pythagoras took from Abaris, the Hyperborean [dweller in the extreme north], his golden dart, without which it was impossible for him to find his road." According to Gaubil, the directive tendency of the needle was known to the Chinese as early as the Dynasty of Haz, A.D. 223. Alexander Humboldt also ascribes an early knowledge of this fact to the Chinese, who

Jamlichus.

Directive tendency of magnetic needle said to have been known to Chinese A. D. 223

Humboldt.

are reputed to have had sailing craft in the Indian Ocean that were under the guidance of a magnetic needle at least 700 years before the compass was used by European nations.

A rude form of compass is said to have been invented at a very early date, in northern Asia, and to have been carried by the Tartars to China. These same Tartars are credited with the use of a miniature figure of a man resting on a pivot, and holding in his hand a small magnet, so arranged that the figure always pointed to the south. It was by the use of such a figure that the Tartars found their way across the grassy plains that covered extended portions of their territory. It would seem, therefore, that at a very early date, the directive power of magnetism was practically employed by the Chinese. Although they were unacquainted with the fact that magnetism was the cause of this phenomenon, yet they knew that the strange power of the lodestone could readily be imparted to a piece of steel by merely rubbing the steel against the stone. In the Chinese and Japanese languages, there are terms employed for the magnet which signify "stone for rubbing the needle," and the "stone for rubbing the steel needle."

Rude form of compass employed by Tartars for guidance over the land.

Lodestone employed for imparting its powers to steel by rubbing.

According to a French poem found in a curious quarto manuscript of the fifteenth century, statements occur which show that the mariner's compass was known at least during the twelfth century. In a History of Jerusalem, by Cardinal de Vitry, published about A.D. 1200, mention is made of the great value of the mariner's compass to those who travel much on the water.

Reference to compass made in publication, A.D. 1200.

Guiot de Province on use of touched needle in navigation.

Guiot de Province, in one of his poems, states that before the year A.D. 1200 mariners employed a

"touched" needle, mounted on a piece of straw, to guide them over the ocean.

Employment of compass by Syrian navigators, A.D. 1242.

As early as 1242, navigators on the Syrian seas employed for determining their direction a compass needle, consisting of an ordinary sewing needle that had been touched by a lodestone. This needle was mounted on a piece of cork, and allowed to float on the water surface. According to Sir William Snow Harris, the length of this needle was subsequently increased to about six inches, and the needle suspended on a point in a white china dish or bowl filled with water, probably, to prevent it from falling to the side of the vessel. A much later reference is made by Adams, in the fourth volume of his "Natural Philosophy,"published in 1794, in which he declares Verstomanus affirms that during A.D. 1500 he saw an East Indian pilot determine the course of his ship by means of the directive tendency of a magnet, and claims that the arrangement of such needle or compass was not unlike that used at the present time. In A.D. 1269 Adsiger refers to a compass needle mounted on an axis, and calls attention to the declination of the compass needle, that is, of its failure to point to the exact geographical north.

Use of needle in navigation by East Indian pilot in A.D. 1500.

Invention of compass by Flavio Gioi, of Principati, in A.D. 1320.

According to others, a Neapolitan, named Flavio Gioi, who lived in the Thirteenth Century, is believed to have invented the compass needle about 1320. Gioi was a nobleman in the city of Principati, which has since that time borne a representation of a mariner's compass on its coat-of-arms.

Paulus Venetus and the compass in Italy in A.D. 1260.

Gilbert, in his "De Magnete," published in 1600, asserts that Paulus Venetus brought the mariner's compass from China to Italy in A.D. 1260.

In 1492, Columbus, in the famous voyage in which he made the discovery of America, observed the variation of the magnetic needle, or its failure to point to the north in all parts of the earth. As we have already mentioned, the fact of the variation of the compass was noticed long before the time of Columbus, but it was this intelligent navigator, who first discovered that the amount of this deviation was by no means a constant quantity, but varied in different parts of the earth. At a somewhat later date, 1497, Sebastian Cabot discovered that the deviation of the compass was real, and had the same value for the same magnetic needle in the same parts of the earth.

Discovery of the variation of the compass by Columbus in A.D. 1492.

Further observation on variation of the compass in A.D. 1497.

Irving, in his "Life and Voyages of Columbus," volume one, page 291, thus refers to the effect produced on Columbus and his companions when they first noted that the magnetic needle was apparently losing its directive power:

Irving's "Life of Columbus" on the variation of the compass needle.

"On the 13th of September, 1492, he [Columbus] perceived about nightfall that the needle, instead of pointing to the north star, varied about one-half a point, or between 5° and 6°, to the northwest, and still more on the following morning. Struck with this circumstance, he observed it attentively for three days, and found that the variation increased as he advanced. He at first made no mention of this phenomenon, knowing how ready his people were to take alarm; but it soon attracted the attention of the pilots, and filled them with consernation. It seemed as if the laws of nature were changing as they advanced, and that they were entering into another world, subject to unknown influences. They apprehended that the compass was about to lose its mysterious virtues, and without this guide, what was to become of them in a vast and trackless ocean?

Columbus tasked his science and ingenuity for reasons with which to allay their terrors. He told them that the direction of the needle was not to the polar star, but to some fixed and invisible point. The variation was not caused by any failing in the compass, but by the movement of the North Star itself, which like the other heavenly bodies, had its changes and revolutions, and every day described a circle round the pole. The high opinion that the pilots entertained of Columbus, as a profound astronomer, gave weight to his theory, and their alarm subsided."

Explanation of Columbus as to cause of variation of the compass needle.

If a magnetic needle is mounted so as to be able to move freely in a vertical as well as in a horizontal plane, it will not remain in its horizontal position like an ordinary compass needle, but will incline or dip toward the earth. This deviation is called the inclination or dip of the magnetic needle. This inclination was discovered in 1576, by Robert Norman, a practical optician of London. Norman noticed the dip or inclination of the needle at this time was nearly 72°.

Inclination or dip of the magnetic needle.

Norman thus describes his discovery of the dip of the needle:

"Having," says he, "made many and divers compasses, and using always to finish and end them before I touched the needle, I found continually that after I had touched the yrons [irons] with the stone, that presently the north point thereof would bend or decline downward under the horizon in some quantity; inasmuch, that to the flie of the compass, which before was made equal, I was still constrained to put some small piece of wax in the south part thereof to counterpoise this declining, and to make it equal again.

Norman's discovery of the dip of the magnetic needle at London, England, in 1576.

"Which effect having many times passed my

hands without any great regard thereunto, as ignorant of any such property in the stone, and not having heard or read of any such matter; it chanced at length that there came to my hands an instrument to be made with a needle of six inches long, which needle, after I had polished and cut off at just length and made to stand level upon the point, so that nothing rested, but only touching of it with the stone; when I had touched the same presently the north part thereof declined down in such sort that being constrained to cut away some of that part, and to make it equal again, in the end I cut it too short, and so spoiled the needle wherein I had taken so much pains.

How Norman spoiled a magnetic needle in his endeavor to prevent it from dipping or inclining to the earth.

"Here by being stroken into some choler, I applied myself to seek further into this effect, and making certain learned and expert men (my friends) acquainted in this matter. They advised me to frame some instrument, and to make some exact trial how much the needle touched with the stone would decline, or what greatest angle it would make with the plane of the horizon."

The variation of the compass was known to the Chinese long before the time of Columbus. In a Chinese book on Medicine and Natural History, by Keu-tsoung-Chy, written about A.D. 1111, the following occurs:

Note on the variation of the compass needle in Chinese at about 1111 A.D.

"When a steel point is rubbed with a magnet it acquires the property of pointing to the south: yet it declines always to the east, and hence does not point straight to the south. If the needle be passed through a wick (made of rush) and placed on water it will also indicate the south, but with a continual inclination toward a point 'ping,' or five-sixths to the south." This was the variation at Pekin at the time the observation was made.

Magnetization of iron by earth's magnetism, aided by lightning stroke.

The first published notice of the production of magnetism in a bar of iron by a lightning stroke was made by Gassendi in 1630, who notes that a bar of iron which had been in the same position for many years and had been struck by lightning, possessed magnetic properties. We now know that either the lightning or the mere resting of the iron on the earth might have magnetized the bar.

Wilkins in "The Secret and Swift Messenger."

The mysterious power possessed by the lodestone to act at a distance has led to many curious suggestions as to what might be possible. In a publication entitled, "The Secret and Swift Messenger," by Bishop Wilkins, the suggestion of one Famianus Strada is given:

Curious suggested invention of Famianus Strada.

"Let there be two needles provided of an equal Length and Bigness, being both of them touched by the same lodestone; let the Letters of the Alphabet be placed on the Circles on which they are moved, as the Points of the Compass under the needle of the Mariner's Chart. Let the Friend that is to travel take one of these with him, first agreeing upon the Days and Hours wherein they should confer together; at which times, if one of them move the Needle, the other Needle, by Sympathy, will move unto the same letter in the other instantly, though they are never so far distant; and thus by several Motions of the Needle to the Letters, they may easily make up any Words or Sense which they have a mind to express."

Testimony of early myths, legends and folk-lore to early knowledge of magnetism.

Additional historical references to different discoveries and inventions in the early history of magnetism will be made under their proper heads in different parts of this book. It will be interesting, however, before closing this chapter on the early history of magnetism, to refer briefly to some myths,

legends and folk-lore concerning early ideas regarding this extremely interesting branch of physical science. As regards the lifting power of magnets, Guillemin, in his "Electricity and Magnetism," states, that according to Pliny, when Ptolemy Philadelphus and Dinochares, his architect, had prepared for Queen Arsinoe the plan of a temple, they arranged to have the entire arch built of lodestone, so that an iron statue of the Goddess should remain suspended to the ceiling by simple contact.

St. Augustine states that in certain countries the Pagan priests, in order to deceive the people, had placed strong magnets, both in the arch of the temple and in the floor directly below the arch, so that the two opposite attractions held suspended in midair an iron statue without any apparent means of support.

St. Augustine on deception practiced by Pagan priests.

The legend of Mahomet's coffin, which was made of iron, being suspended from the ceiling of the mosque in which he was buried, is known to nearly all. Another statement refers to this coffin as being held in mid-air, with no visible means of support, by means of magnets placed both in the ceiling and floor, directly above and under the iron coffin.

Legend of Mahomet's coffin.

Somewhat in this same line, an early account is given in a quaint book published in 1708, by John Wilkins, Bishop of Chester, and taken from volume II. of "Kircher de Arte Magnetica," describing in detail a toy well known to-day in philosophical cabinets. "Get a Glass Sphere, fill it with such Liquors as may be clear of the same Colours, immixable, such as Oyl of Tartar or Spirit of Wine; In which it is easie so to poise a little (iron) Globe or other statue, that it shall swim in the Centre. Under this Glass

An actual toy, Mahomet's coffin.

Sphere there should be a lodestone concealed by the Motion of which this statue (Having a Needle touched within it), and may be constrained to show the Hour or Sign."

The following examples taken from common legend, or folk-lore, show how common was a belief in the occasional existence of unusually large masses of lodestone in certain parts of the earth. The following is mentioned by Guillemin in his "Electricity and Magnetism":

Legend of the mountain of lodestone.

"Tales of another kind show how people were astonished by the curious property of magnetic attraction. 'The celebrated astronomer and geographer, Ptolemy, says, from public report, the truth of which, by the way, he does not warrant, that the ships which go to the Manioles Isles would have been held there if they had not taken the precaution in building them to use bolts of wood instead of iron nails. Ptolemy asks if this was caused by the large mines of lodestone in the islands?' After Ptolemy has assigned the position of the Manioles, between Taprobanus and the Golden Chersonese (Ceylon and Malacca), they without doubt are in the archipelago of Andaman or Nicobar. 'According to Pliny there are near the Indus two mountains, one of which attracts iron and the other repels it; at a certain position a traveller who has nails of iron in his boots on one of the mountains can not place his feet on the ground, while on the other his feet remain fixed to the ground.'"

Arabian Nights story of Agib, son of King Cassib.

The following is taken from that charming combination of vivid Eastern imagination, early myths, and curious folk-lore, called the Arabian Nights. We refer to the adventures of Agib, son of King Cassib, as told in the story of the Third Royal Calender.

Agib tells of a storm which drove the ship, on which he was a passenger, out of its course, and brought it within the alleged attractive power of a mountain of lodestone; but we prefer to let Agib tell his own story.

"'Alas!' cried the pilot, 'the tempest which we have outlived, has so driven us from our track, that by mid-day to-morrow, we shall find ourselves near that blackness, which is a mountain consisting entirely of a mass of lodestone, that will soon attract our fleet, on account of the bolts and nails in the ships. To-morrow, when we shall have come within a certain distance, the power of the lodestone will be so violent, that all the nails will be drawn out, and fastened to the mountain: our ships will then fall in pieces and sink. As it is the property of a lodestone to attract iron, and at the same time to increase its own power by this attraction, the mountain toward the sea is entirely covered with nails that belonged to the infinite number of ships, which it has been the means of destroying; and this, at the same time, both preserves and augments the power of its agency.

Consternation of the pilot.

Tale of the terrible mountain of lodestone.

"'This mountain,' continued the pilot, 'is very steep; and on the summit there is a large dome made of fine bronze, which is supported upon columns of the same metal. Upon the top of the dome there is also a bronze horse with the figure of a man upon it. A plate of lead covers his breast, upon which there are some talismanic characters engraven; and there is a tradition, Sire,' added he, 'that this statue is the principal cause of the loss of so many vessels and men as have been drowned in this place, and will never cease from being destructive to all who shall have the misfortune to approach it, until it be overthrown.' The pilot having finished his speech renewed his tears, which excited those of the whole

How the lodestone mountain wrecks ships.

crew. For myself, I did not doubt that I had arrived at the end of my days. Every individual now only thought of his own preservation, and used every possible means conducive to that end: and, during the uncertainty of the event, they all appointed, by a sort of will, the survivors, if any should be saved, the heirs of the rest.

"The next morning we distinctly perceived the black mountain; and the idea we had formed of it made it appear still more dreadful than it really was. About mid-day we found ourselves so near it, that we began to perceive what the pilot had foretold. We saw the nails and every other piece of iron belonging to the vessels, fly toward the mountain, against which, by the violence of the magnetic attraction, they struck with a horrible noise. The vessels in a little time fell to pieces and sunk to the bottom of the sea; which was so deep in this place that we could never discover the bottom by sounding. All my people were lost; but God had pity upon me, and suffered me to save myself by laying hold of a plank, which was driven by the wind directly to the foot of the mountain."

Arrival at the lodestone mountain and the destruction of the fleet.

CHAPTER XV

MAGNETIC ATTRACTIONS AND REPULSIONS

"'Twas thus, if ancient fame the truth unfold,
Two faithful needles, from the informing touch
Of the same parent stone, together drew
Its mystic virtue, and at first conspired
With fatal impulse quivering to the pole."
—*Pleasures of Imagination:* AKENSIDE

AS we have already seen, the mysterious power possessed by the lodestone, of attracting and drawing to it particles of iron, while it apparently was indifferent to all other substances, drew the attention of the curious to these phenomena at a very early date. Indeed, even in our time this power still causes much wonderment, a wonderment which is intensified by the power of the magnet to apparently reach across empty space and act on bodies situated at fairly considerable distances. This latter-day wonderment of the world, at the action of magnetism, is not surprising when we remember that, although much has been learned concerning the action of this mysterious force, yet even to-day we are almost as far as ever from knowing certainly its exact nature.

Early wonderment at strange powers of magnetism still existing.

One of the simplest ways to show the power possessed by the lodestone to attract and draw iron toward it, is to roll a lodestone in iron filings, which will then be drawn to the stone, and adhere to it in

tufts, as shown in Fig. 79. Here an examination of the stone will show that the filings have collected mainly at the two opposite ends, few or none col-

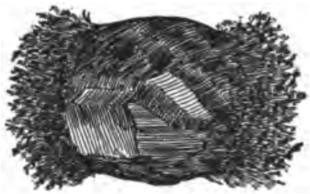


FIG. 79.—Appearance produced in a small specimen of lodestone by rolling it in iron filings. Note the fact that the filings collect mainly on the two opposite ends only. These ends show the position of the N and S poles of the lodestone.

Appearance of lodestone produced by rolling it in iron filings.

lecting at intermediate points on the surface. These two ends where the filings collect are called the poles of the lodestone, and are called respectively the north and south poles, according to the direction in

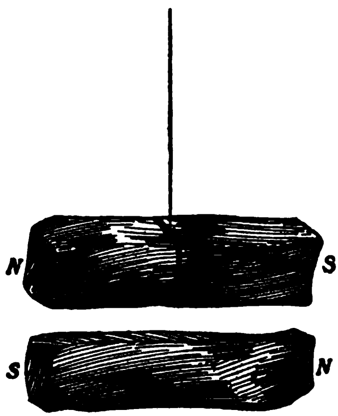


FIG. 80.—Natural magnet formed of a piece of lodestone suspended by a thread, in order to show its directive tendency, or the fact that such a stone comes to rest only when its end N points approximately to the geographical north.

North and south poles of a piece of lodestone.

which the poles or ends will point. If the lodestone be suspended by a string, as shown in Fig. 80, so as to be free to move, the pole which points, approximately, to the geographical north is called the north

pole of the lodestone, and the other pole the south pole. Small iron nails, tacks, or steel needles may be employed in place of the iron filings in the above experiment.

In order to obtain the best attractive effects from a lodestone it is customary to mount on its poles pieces of soft iron, as shown in Fig. 81. Here the lodestone is placed in the frame consisting of some non-magnetic material, like copper, and is armed at its two poles with plates of soft iron. A is the lodestone, and B, B are two plates of soft iron

Lodestone provided with soft-iron armature.

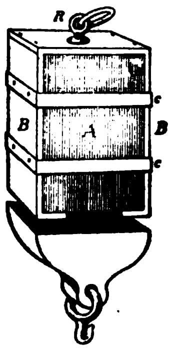


FIG. 81.—Lodestone with plates of soft iron placed against its poles, bent inward, and provided with an armature of soft iron. Note that the soft-iron plates B, B bring the opposite poles nearer together, so that both of these poles attract the soft iron of the armature.

placed against its opposite poles with the lower ends turned inward, as shown. The north and south poles, thus brought near together at the lower end of the magnet, are provided with a plate of soft iron called the armature. The ring R, at the top, is provided for suspending the magnet. A hook is placed at the lower end of the armature, on which is hung the weight the magnet is to carry.

As we have seen, when a piece of hardened steel

is rubbed, stroked, or touched by either of the poles of a lodestone it at once acquires the properties of a magnet. Magnets obtained in this manner are called artificial magnets, in order to distinguish them from lodestones, or natural magnets.

Artificial and natural magnets.

Artificial magnets are made in a variety of shapes. The simplest of these is the bar magnet. Such magnets are generally so touched or stroked as to cause their north and south poles to come at the opposite extremities of the bar. In order to increase the

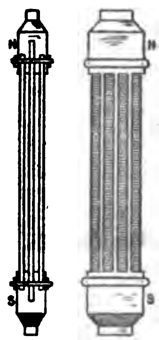


FIG. 82.—Compound Bar Magnet or Magnetic Battery. Note the heavy armatures N and S placed where all the N and S poles respectively end.

strength of the poles, artificial magnets are often made by combining a number of separate magnets made of thin plates of hardened steel, with their like poles placed together. Such magnets are called compound magnets, or magnetic batteries. A compound bar magnet is shown in Fig. 82. Here all the north poles are placed over one another, and provided with a single armature N, and all the south poles similarly placed together, and provided with the single armature S. Compound magnets will carry a greater weight than will single magnets of the same weight. This method of increasing the

Compound magnets or magnetic batteries.

strength of magnets was first proposed by Scoresby. Jamin, of Paris, has produced very powerful laminated or compound magnets. **Jamin's compound magnets.**

When a bar magnet is bent so as to bring its opposite poles near together, it forms what is called a horseshoe magnet, so named on account of its shape. This is a very common form of artificial magnet. A horseshoe magnet will bear a much greater weight than an ordinary magnet of the same size, on ac- **Compound horseshoe magnet.**

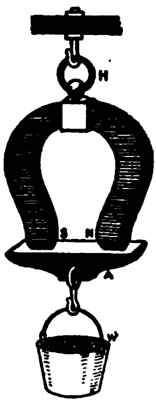


Fig. 83.—Compound Horseshoe Magnet, or Magnetic Battery. The armature A is acted on by the magnetic poles S and N.

count of its opposite poles being brought nearer together, so as to permit both poles to act on the armature, or on the mass of soft iron that may be brought near it. The compound horseshoe magnet is shown in Fig. 83.

In order to study the power of magnets to both attract and repel other magnets, a form of magnet called a magnetic needle is employed. This consists, as shown in Fig. 84, of a thin, slender bar of hard- **Magnetic needle.**

ened steel, tapering at its ends, and so magnetized as to produce its north and south polarity at these ends. This needle is provided at its centre with a cap of glass, agate, or other hardened material, which will enable it to be supported on a needle point, so as to move with very little friction. When such a magnetic needle is placed on its supporting pivot, it will, if not in the neighborhood of some other magnet or mass of iron, come to rest in a horizontal position, with its north end or pole pointing, approximately, to the geographical north. This tendency of

Directive tendency of suitably supported magnetic needle.

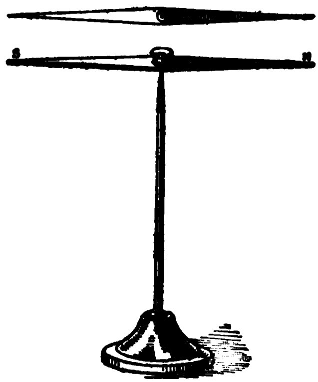


FIG. 84.—Magnetic Needle. The agate or glass cup is placed at the centre of the needle, so as to support the needle in a horizontal position on a needle point, as shown in the lower part of the figure.

a freely movable magnetic needle to thus point, approximately, to the geographical north, is called the directive tendency of the magnetic needle. Such a needle constitutes practically a mariner's compass.

A bar of soft iron brought near to either pole of a magnetic needle at rest, will attract, or draw the needle toward it, no matter to which pole of the needle it is first approached. Now suppose there are two needles, each mounted on its pivot, and far

enough apart for each to point, approximately, to the geographical north. Lift one of these needles from its support and hold it in the hand. Now, calling as before those ends of the needles which point, approximately, to the geographical north, their north poles, and the opposite ends their south poles, if we bring the north pole of the needle held in the hand near the north pole of the supported needle a repulsion will take place. If we approach the south pole of the needle held in the hand to the north pole of the supported needle an attraction will take place. In the same way the two south poles will repel each other, while the north pole of the needle held in the hand will attract the south pole of the supported needle. In other words, we have demonstrated the first law of magnetism; viz., that magnetic poles of the same name repel each other, and that magnetic poles of opposite names attract each other.

Experiment in the first law of magnetism; viz., like magnet poles repel, and unlike magnet poles attract, each other.

If a straight bar magnet be rolled in iron filings the filings will collect, as shown at A in Fig. 85, at or near the poles S and N only, and a space will be left in the middle of the bar that is devoid of iron filings. Moreover, if a small magnetic needle be used as a variety of magnetic explorer, to move along the bar magnet from one pole to the other, without touching the bar, it would seem as if one entire half of the bar magnet, from, say the north end to the middle of the bar, possessed north magnetism only, and the other half, south magnetism only; since, from the north end to the middle point, the south end of the exploring needle will point to the bar magnet, while the other half will appear to possess south magnetism only, since through all this half the north end of the exploring magnet points to the bar. The middle of the magnet only seems to possess no magnetism, and is, therefore, called the

Distribution of magnetism in a bar magnet determined both by means of iron filings and by the use of a magnetic exploring needle.

neutral point of the magnet, or the magnetic equator. Moreover, it would appear that the magnetism of the bar magnet is strongest at its ends, and decreases in strength gradually toward this neutral point or equator.

Impossibility of obtaining a magnet with one pole only, or a unipolar magnet.

It would seem, therefore, to be an easy thing to obtain a magnet of a single polarity only, that is, a magnet possessing the north or south magnetism only. On trial, however, it was found that this could not be done; for, if such a bar magnet were suddenly divided or cut into two equal parts, it was found that the separated magnets, instead of possessing north or south magnetism only, possessed

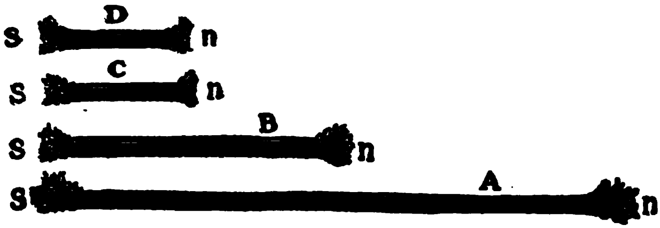


Fig. 85.—Polarity of Bisected Magnet. Note that the neutral point where the magnet is cut or divided now shows two opposite poles, of magnetic strength equal to that at their far ends, as indicated by the amount of iron filings at both ends of the bisected magnets.

magnetic poles at the cut extremities, as strong as at their opposite ends, and, that if such cut magnets were rolled in iron filings the filings would collect in as great a mass at the cut ends as at their other extremities. This is represented in Fig. 85, where a single bar magnet at A possesses two poles, south and north, as shown by the collection of iron filings. When, however, this bar is cut into halves, each of these halves, as shown in the figure at B, possesses poles of equal strength, *s* and *n*, at the extremities, and the same is true if this half be cut into quarters, as shown at C and D. It is impossible, therefore, to

obtain a unipolar magnet, or a magnet possessing one polarity only; *i.e.*, north magnetism or south magnetism only. No matter how small a magnet may be, if it possess north polarity it must at the same time possess the opposite or south polarity.

But, while it is impossible for a magnet to have a single pole only, it is apparently not impossible for a magnet to possess three, five, or any odd number of separate poles. This, however, is only apparently the case, for such magnets are in reality formed by two or more magnets with their like poles placed together, when, of course, the resulting magnet must

Anomalous magnet, anomaly only apparent.

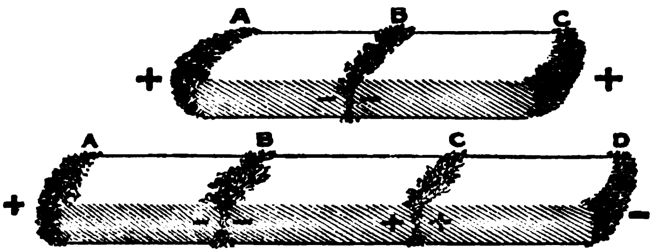


FIG. 86.—So-called anomalous magnets, with three and four poles respectively.

necessarily possess twice as many poles as the number of separate magnets so placed together. This is shown in Fig. 86, where, at the top of the figure, two separate magnets, AB and BC, are placed with their two south poles together. There is thus produced a magnet with apparently three poles only, but a more careful examination will show that in reality the magnet possesses four poles, since the central pole consists of two opposed south or — poles. Such a magnet is sometimes called an anomalous magnet, from the apparent anomaly of the magnet possessing an odd number of poles. In the same way, at the bottom of the figure, is shown

how three separate magnets, placed together, will produce not six poles, but four poles only, since two of the intermediate poles; *i.e.*, those at B and C, consist of two similar — or south poles at B, and two similar + or north poles at C. It will be noticed here that in magnetism, a positive or north polarity, like a positive charge of electricity, is represented by a plus sign, +, and a negative or south polarity, like a negative charge of electricity, by the minus sign, —.

Magnetic induction. We have seen that when either a piece of hardened steel, or a piece of soft iron, is brought into contact with the pole of a magnet it is made to receive

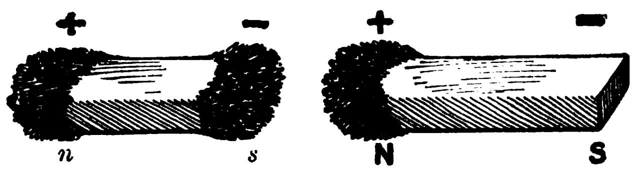


FIG. 87.—Magnetic Induction. Note that an opposite polarity is produced by induction. Magnetic induction invariably precedes magnetic attraction.

magnetism. It is not, however, necessary that the two metals be brought into actual contact. The piece of steel or iron will become a magnet if it be merely brought into the neighborhood of the magnet without touching it. If, for example, as in Fig. 87, a bar of unmagnetized steel, N S, be brought near a bar magnet, *n s*, it will without touching it have a north, or plus, pole, N, produced at the end nearest the south, or minus, pole of *n s*, as may be shown by sprinkling iron filings. Here an opposite pole, S, is also produced at the end furthest from N, but not indicated in the figure by the presence of iron filings. The production of magnetism in this way is called induction, and the magnet, *n s*, is called the inducing

Magnetization by induction the same phenomenon as magnetization by touch.

magnet, and is said to induce magnetism in the bar N S. The nearer we bring the two bars together the more powerful are the effects produced by induction. When they touch one another these effects are greatest. The production of magnetism by touch is, therefore, only a case of the production of magnetism by induction.

In the case of magnetic induction just described, the medium between the inducing and the induced magnets was the air. Many other media, however, permit magnetic induction to take place through them; for example, a bar magnet will readily induce magnetism through a sheet of glass or through a china plate, a wooden board, or several sheets of paper. In this respect it is like electro-static induction, which, as we have seen, can take place through glass, sulphur, shellac, hard rubber, and a number of other dielectrics.

Magnetic induction possible through glass, china, wood, etc.

Hardened steel and soft iron are not the only metals that can receive magnetism by induction. The following metals are also readily magnetized, viz., nickel, cobalt, chromium, cerium, and manganese.

The magnetic metals.

Both soft iron and hardened steel can readily be magnetized. They differ, however, in this respect, that while soft iron receives its magnetism very readily, it also immediately loses its magnetism as soon as it is removed from the magnetizing pole. On the contrary, hardened steel, although more difficult to magnetize, yet retains its magnetization practically for an indefinite time after its removal from the magnetizing pole. The ability of substances to retain their magnetism is called their magnetic retentivity, or magnetic memory. It was formerly

Magnetic retentivity, or magnetic memory.

called coercive force. The magnetic retentivity of soft iron is very small. In other words, its magnetic memory of its past magnetic condition is small. The magnetic retentivity of hardened steel, however, is great. Changes of temperature alter the magnetic retentivity. If a piece of hardened steel be annealed, *i.e.*, heated, and then permitted to cool slowly, so as to become soft, its magnetic retentivity decreases. On the other hand, if it be highly heated and then quickly cooled by placing it suddenly in cold water, it becomes hardened, and its magnetic retentivity increases.

Influence of temperature on magnetic retentivity of iron and steel.

The readiness with which soft iron both receives and parts with its magnetism is shown by the fol-

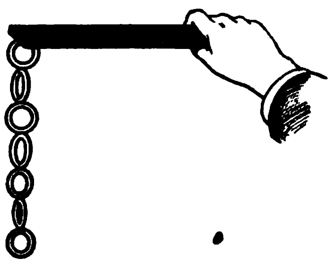


Fig. 88.—Experiment of the pendent chain, showing the very small magnetic memory of soft iron. When the upper ring is separated from the supporting magnet pole, all the rings instantly forget that they had been magnetized and drop apart from one another.

lowing experiment. Suspend a small piece of soft iron, such, for example, as a ring, to one of the poles of a bar magnet, as shown in Fig. 88. From this a number of separate rings may be successively suspended, as shown in the figure. As soon as the ring is brought into contact with the magnet pole or another ring, it becomes magnetic, but when a separation is effected between the first ring and the magnet pole all the rings instantly lose their magnetism, and no longer attract one another.

Experiment showing the small magnetic retentivity of soft iron.

In general the strength of a steel magnet is decreased by an increase in its temperature. On the contrary, cooling a magnet generally increases its strength. If the temperature of a steel bar magnet is raised too high, it will lose all its magnetism. Soft iron can not be magnetized while at a red heat. On cooling, however, it again acquires the power of being magnetized. A curious effect is noticed in an alloy of steel and nickel consisting of three parts of iron and one part of nickel. At ordinary temperatures this substance is non-magnetic, but when heated to about 1100° F. and then allowed to cool, it can be magnetized. If, however, this cooling be carried below 39.2° F. it becomes non-magnetic, but can, however, by reheating to 1100° F. and subsequent cooling, regain its ability to be magnetized.

Effects of temperature on magnetism.

Curious effect of temperature on magnetism of a certain alloy of iron and nickel.

The presence of certain substances in a mass of iron prevents the alloy from being magnetized; for example, an alloy of iron and manganese containing 12 per cent of manganese, and known as manganese steel, is almost incapable of being magnetized, although containing 88 per cent of the highly magnetizable substance, iron.

Presence of manganese in manganese steel masks the magnetic properties of the iron present.

CHAPTER XVI

THEORIES OF MAGNETISM. MAGNETIC FLUX. MAGNETIC FORCE

"If we observe the lines of force between two magnets, as indicated by iron filings, we shall see that, whenever the lines of force pass from one pole to another, there is attraction between these poles; and where lines of force from the poles avoid each other, and are dispersed into space, the poles repel each other, so that, in both cases, they are drawn in the direction of the resultant lines of force."—MAXWELL

IN 1759, Æpinus proposed, for the explanation of the phenomena of magnetism, a theory that greatly resembled Franklin's single-fluid theory for electricity. Æpinus asserted that in all magnets there exists a peculiar magnetic fluid, the particles of which are mutually repellent, but are attracted by the particles of iron, or other magnetic substances; that all such substances contain a certain amount of this magnetic fluid, which is distributed so evenly throughout their mass that they do not exhibit any magnetic properties, showing neither attraction nor repulsion, because the repulsion existing between the particles of the magnetic fluid is exactly balanced by the attraction between the particles of the magnetized substance. When, however, such a substance is magnetized, say, for example, a bar of hardened steel, the magnetic fluid is driven to one end of the bar, which thereby acquires north polarity, while the other end becomes of south polarity, on account of the absence of the magnetic fluid. The fact already mentioned, as to the impossibility of obtaining

Æpinus's single-fluid theory of magnetism.

Why any fluid theory of magnetism is untenable.

a magnet with a single polarity, makes it impossible to believe in any fluid theory of magnetism.

In 1780, Coulomb, the inventor of the torsion balance, proposed a double-fluid theory of magnetism, in which he ascribed the cause of magnetism to two separate and distinct magnetic fluids, naturally present in the invisible particles or molecules of the iron. These fluids were the boreal, or north magnetic fluid, and the austral, or south magnetic fluid. The molecules of an unmagnetized bar are arranged in so irregular a manner that the opposite polarities of the two separate fluids neutralize each other, but when magnetized, all these particles are turned so that their poles point in one and

Coulomb's double-fluid theory of magnetism.

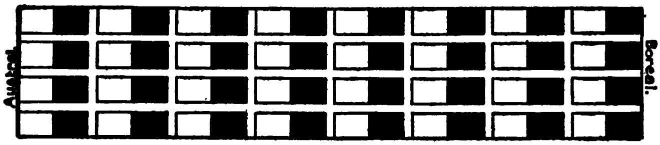


Fig. 89.—Constitution of magnetized bar, according to Coulomb's double-fluid theory, showing the alignment of all of its separate molecular magnets.

the same direction, as shown in Fig. 89, where a few only of the innumerable particles in a bar magnet are represented. A careful study of such an arrangement of particles will show that the bar would possess magnetic polarities at its ends, and that the magnetic strength would decrease toward the centre, where a point of no magnetism would be found, since here, the opposite attractions of the separate molecular magnets would neutralize each other. Such a theory would also explain how a bar magnet, when suddenly cut or divided at its neutral point, should manifest strong poles at the cut portions, since then the opposite attractions would no longer neutralize the separate magnets at this point.

How Coulomb's theory of magnetism accounts for the phenomena of the bisected magnet.

It is impossible to believe in any fluid theory of magnetism, since the ability of a magnet to produce magnetism in other bodies by induction is unlimited. A magnet can produce an indefinite quantity of magnetism in other bodies without losing or parting with any of its own magnetism. This fact is inconsistent with the belief that its cause is to be ascribed to a fluid.

Weber, Maxwell, Ewing and Ampère and their theories of magnetism.

While Coulomb's theory, as above described, has been generally discredited, so far as it attributes the magnetism of the molecules to the presence of north and south magnetic fluids, yet, in a modified form, it has been proposed at a much later date by a number of physicists, with, however, the exception that the molecules, or even the smaller particles of matter, are regarded as naturally possessing magnetism. Such are practically the theories proposed by Weber, Maxwell and Ewing. Ampère, as we shall see further on in this book, when we are better able to understand the phenomena to which he alludes, goes so far as to attempt to explain how the molecules or ultimate particles of a magnet acquire their magnetism.

Explanation of partial magnetization and saturation.

According to all of these theories, substances become magnetized to their full extent when all the molecules are turned or aligned in the same direction; or, in other words, the magnet is said to be saturated, while a partial magnetization consists in only a partial orientation or alignment of the molecules. The difference in the behavior of soft iron and hardened steel can also be readily explained by this theory, since in soft iron the molecules need only be supposed to be readily turned or aligned, while in hardened steel they are supposed to be turned or aligned only with difficulty. So, too, the difference in retentivity, or coercive force, can also be ex-

plained, since these molecules either return readily or only with difficulty to their undirected condition, after having been magnetized or aligned. The effects of temperature can also be explained by such theories, from the difference in the ease with which the molecules can be aligned or caused to point in one and the same direction. The annealing, as well as the hardening of the steel or other magnetizable substances, would also necessarily affect the readiness with which they both receive and part with their magnetism, from a change in the readiness with which their molecules can be turned by the action of the magnetizing force.

Why changes of temperature affect magnetic retentivity.

Why annealed and hardened steel differ in their magnetic retentivity.

There is, however, a still more modern theory of magnetism that is gradually gaining ground among scientific men. We say more modern theory, although, like many such theories, it is only an old theory presented in a more modern garb. Briefly, this theory ascribes the phenomena of magnetism to the presence of streamings, whirlings, or vortices set up by a magnet within its entire mass, as well as in the ether surrounding it.

Theory of magnetic streamings, or vortices.

Before entering more fully into this theory of magnetism, a few words will be given here as to the early date at which such a theory was partially proposed. Cornelius Gemma asserted that, during the action of a magnet on a mass of iron, invisible rays passed between the magnet and the iron. Plutarch thought that there was an emanation which proceeded from a magnet. Descartes applied to magnetism his theory of vortices, a theory in which he supposed all space to be filled with matter. That all bodies excited or influenced other bodies in the space around them by setting up in that space whirlings or vortices. It does not appear, however, that Des-

Cornelius Gemma on invisible rays emanating from magnet.

Descartes's theory of magnetic vortices.

cartes's ideas were at all clear as to just how his theory should be applied to the phenomena of magnetism.

A general belief existed in ancient times as to the existence of effluvia, that is, of matter in a state of extremely high attenuation, which passed off from all bodies, and gave rise to many of their peculiar properties. The cause of magnetism was attributed, by Robert Boyle, as early as 1668, to effluvia given off from a magnet. This will be seen from the following quotation taken from the second of two essays "Concerning the Unsuccessfulness of Experiments":

Magnetic effluvia.

"If on either of the Extremes or Poles of a good armed Load-stone, you leisurely enough, or divers times, draw the back of a Knife, which has not before received any Magnetick influence, you may observe, that if the point of the blade have in this affriction been drawn from the middle or Equator of the Load-stone towards the Pole of it, it will attract one of the Extremes of an equilibrated Magnetick Needle; but if you take another Knife that has not yet been invigorated, and upon the self-same Extremity or Pole of the Load-stone, thrust the back of the Knife from the Pole towards the Equator or middle of the Load-stone, you shall find, that the point of the Knife has, by this bare difference of Position in the blade whilst it past upon the Extreme of the Load-stone, acquired so different a Magnetick property or Polarity, from that which was given to the former Knife by the same Pole of the Load-stone, that it will not attract, but rather seem to repel or drive away that end of the Magnetick Needle which was drawn by the point of the other Knife. And this improbable Experiment not only have we made trial of, by passing slender Irons

Boyle on magnetic effluvia in 1668.

upon the Extremities of armed Load-stones, the breadth of whose Steel-caps may make the Experiment somewhat less strange, but we have likewise try'd it by affrictions of such Irons upon the Pole of a naked terella [a sphere of hardened steel or lodestone, so magnetized as to make the distribution of its magnetism resemble that of the earth], and we have found it to succeed there likewise. How strange soever it may seem, that the same point or part of the Load-stone should imbue Iron with contrary Properties barely as they are, during their passing over it, drawn from the Equator of the Load-stone, or thrust towards it. But whether, and how far this Observation insinuates the operations of Load-stone to be chiefly performed by streams of small particles, which perpetually issuing out of one of its Poles, do wheel about and re-enter at the other; We shall not now examine (though this seem one of the most likely Phænomena we have met with, to hint a probable Magnetical Hypothesis) contenting ourselves to have manifested by what plainly appears, how much influence a circumstance, which none but a Magnetick Philosopher would take notice of, may have on an Experiment."

Boyle's effluvia not unlike magnetic streamings.

Now, on the assumption that the molecules of magnetic matter possess the power of setting up ether streamings in the region surrounding them, a theory capable of explaining the phenomena of magnetism can be readily founded. Suppose, for example, that the molecules of iron which, like the molecules of all matter, are assumed to be in continual rotary or other motion toward and from one another, are through some peculiarity in their structure, able to act like minute air-blowers or fan-motors, so as to set up streaming motions in the surrounding ether. Since ether is frictionless, such

Theory of magnetic streamings as produced by all magnets.

motions, once set up, would continue forever, without the application of any additional force. This theory, like all theories that ascribe magnetism to the molecules of matter, explains magnetization by the directing or aligning of all the ether streams in the same direction, magnetic saturation being reached when all of these streams are similarly directed. Magnetic retentivity, the difference between the behavior of soft iron and hardened steel, the effects of temperature on magnetism, etc., are explained by this theory in a manner similar to the molecular theories above referred to.

How theory of magnetic streamings accounts for magnetic phenomena.

Let us, therefore, examine in the light of the streaming ether theory of magnetism, how some of the phenomena of magnetism already referred to can be explained. Faraday and others, who gave considerable study to magnetic phenomena, disbelieved in the possibility of action at a distance, and attributed the action of magnetic induction to a polarization of the ether, to which he gave the name of lines of magnetic force. The region surrounding a magnet is called a magnetic field, and is permeated or filled with these lines of magnetic force. It is these lines of magnetic force, which this modern theory of magnetism regards as ether streamings, or as magnetic flux. The magnetic flux is assumed to come out of a magnet at one of its poles, and return to it again at the other pole, after it has passed through the magnetic field surrounding the magnet. Simply as a matter of convenience, or as a scientific convention or agreement, these streamings are assumed to come out of a magnet at its north pole, and to re-enter it at its south pole, after having passed through the field of the magnet, as represented in Fig. 90. Here the arrows show the direction of the lines of magnetic force coming out of the north pole and return-

Faraday, and the improbability of action at a distance.

Magnetic fields and lines of magnetic force.

Assumed direction of lines of magnetic force.

ing to the magnet at its south pole, the paths or circuits not being shown in the intermediate space so as to avoid confusion.

The phenomena of magnetic attraction and repulsion can be explained by this theory as follows: When, say, two magnetic needles are brought near each other, they will come to rest only when the magnetic flux is passing in the same direction through both, and this can only occur when their opposite poles are pointing to each other, since in this position only can the flux come out of one pole of one of the needles and enter the nearer pole of the neighboring needle. According to this theory, when

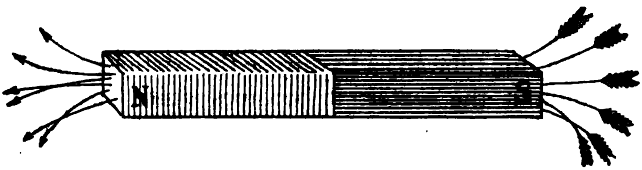


FIG. 90.—Assumed direction of magnetic streamings or lines of magnetic force.

Magnet induction explained by theory of magnetic streamings.

a magnet is rolled in a mass of iron filings, the filings are held to the surface of the magnet in long chains or tufts, in which the separate particles of iron are strung along the lines of magnetic force, not unlike beads on a string. Magnetic induction is also readily explained by this theory. The magnetic flux, coming out of the inducing magnet at its north pole, must necessarily produce a south pole at any part of the magnetizable substance at which it enters; in this case at the end nearest it, while the end at which the flux passes out will possess north polarity. In this case, as in all cases of induction, both the induced and the inducing magnets are strung or grouped on the lines of magnetic force, like beads on a string.

Change in length of bar by magnetization.

When a bar of iron or steel is powerfully magnetized, a small increase occurs in its length, and a decrease in its breadth, the volume of the bar remaining the same. This change is most probably due to a change in the position of its molecules during alignment. Joule has made careful measurements of such changes in length, and found the increase to be $\frac{1}{720000}$ of the length of the bar when magnetized to saturation. Page noticed that the magnetization of a bar is accompanied by a faint clinking sound, due possibly to the movement of the molecules on their alignment. The fact that an alignment of the molecules does occur during magnetization is shown by rendering some clear water, placed in a glass vessel, opaque to light, by the addition of a small quantity of fine iron filings. On shaking this tube so as to diffuse the particles equally throughout the water, it becomes quite opaque to light. But if, while in this condition, it is powerfully magnetized, it becomes partially transparent, from the particles of iron assuming end to end positions on their alignment during magnetization.

Page on sounds produced in a bar on its magnetization.

Proof of alignment of particles of iron filings by their magnetization.

Magnetic figures obtained by aid of glass plates and iron filings.

It is quite possible to obtain clear ideas as to the general direction of the lines of magnetic force, or in other words, of magnetic streamings. This is done by placing a plate of glass over a magnet, sprinkling iron filings on the glass, and then gently tapping it so as to permit the iron filings to arrange themselves in the general direction of the lines of force. These groupings can be permanently fixed to the plate by first covering its surface with a thin sheet of wax, and then melting the wax by heat. Such a sheet of glass, placed over a piece of ordinary photographic silver paper and exposed to the light, will produce a picture of the groupings. It will, however, be a negative picture, in which the positions occupied by

Photographic reproduction of magnetic figures.

the filings are represented as white spaces, and the parts of the plate from which filings were absent, by dark spaces.

A better method of obtaining representations of magnetic lines or streamings is to place a sensitive photographic plate, with its sensitized face upward, in a photographic dark room, over a magnet, say an ordinary horseshoe magnet, sprinkle iron fil-

Method for obtaining good photographic positives of magnetic fields.

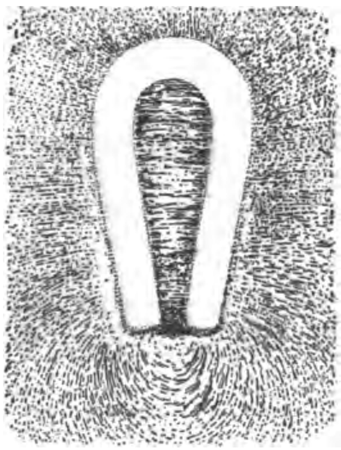


FIG. 91.—Photograph of the Flux Streams or Lines of Magnetic Force of a Horseshoe Magnet.

ings on it, and, when a suitable grouping of these has been obtained, to expose the plate for the fraction of a second to a gas-light or match. On subsequently developing this plate, a photographic negative will be obtained, that is, a picture on the glass in which the lights and shades are reversed, the lights appearing as dark portions on the plate, and the shades as clear portions. If a print be made from this negative on a piece of sensitized photographic paper, an excellent positive picture of the iron filings will be

Photographic positive of horseshoe magnet.

obtained, viz., one in which the filings are represented by dark lines on the white background of the paper. Such a photographic positive is shown in Fig. 91.

How the ether streamings may become visible.

Although the ether streamings surrounding a magnet must ever remain invisible to human eyes, yet, by means of the groupings of the iron filings, we can form a very fair idea of their general directions. An examination of Fig. 91, for example, will reveal the general direction of these streamings, for they have arranged the iron filings along them like beads

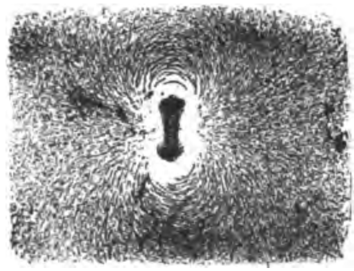


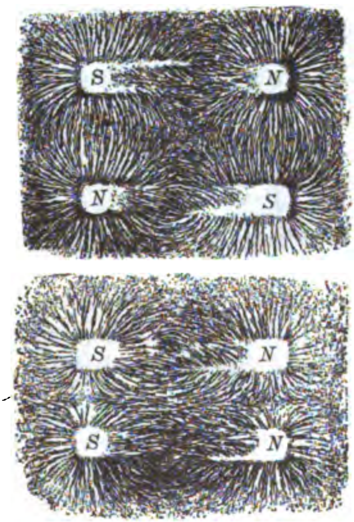
FIG. 92.—Photographic Positive of Magnetic Flux Streams of a Horseshoe Magnet held in vertical position with poles directly below horizontal photographic plate.

on a string. We can, therefore, imagine the streamings coming out of the magnet at certain points, and re-entering it at other points. Of course, it is impossible to say from what points the flux leaves the magnet, and at what points it enters it again. It is for this reason that we have made the assumption that it issues at the north pole, and re-enters at the south pole.

The study of a number of pictures obtained in the above manner will be instructive. Take, for example, Fig. 92, in which a positive has been printed

from a negative obtained by holding a horseshoe magnet in a vertical position, with its poles directly below the lower surface of the photographic plate. Here the flux will be seen to surround the magnet poles in the partially circular paths represented.

It is possible, also, in this way, to picture the magnetic attractions and repulsions existing between



93.—Photographic Positives of Oppositely and Similarly Opposed Magnet Poles.

both oppositely and similarly directed flux. For example, in Fig. 93, are shown the flux paths that are produced in the neighborhood of two parallel bar magnets placed with their poles facing one another. When, as in the upper figure, the magnets are placed with their opposite poles facing one another, it will be noticed that the magnetic streamings pass directly from the north pole of one magnet into the south pole of the opposite magnet. Where, however, as

Magnetic flux picture of similarly and oppositely placed magnet poles.

in the lower figure, they are placed with their similar poles facing, the magnetic streamings are apparently repelled, so that a neutral line is produced, not unlike the line of slack water that would be produced by two oppositely directed water streams. In the region between the two magnets of the upper figure there exists a curious space bounded by curves resembling those that are known in geometry as hyperbolas. Within this space no ether

Space showing no ether streamings.

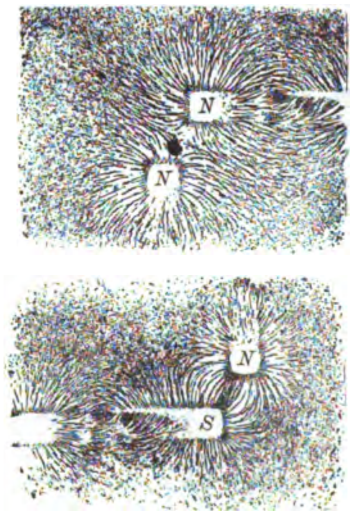


FIG. 94.—Photographic Positives of Fields of Two Separate Magnets. Note in the case of the similarly placed poles the line caused by the impinging of the oppositely directed streams, and the curious region of no motion in the middle of the space between the two magnets.

streamings can penetrate. It, therefore, corresponds to calm water in the case of two streams of water. In Fig. 94 are shown the flux paths produced by the same two bar magnets when placed with the similar and opposite poles, respectively, at right angles to each other.

From the light obtained from the study of these

magnetic flux pictures, we can now much better define a magnet from the standpoint of magnetic flux, or magnetic streamings. A magnet is a body through which magnetic flux or streamings are passing.

That part of the magnet from which the flux emerges is its north pole; that point into which the flux enters is its south pole. Any magnet, therefore, no matter how small it may be, must have one point at which flux enters and another point at which it leaves. It is clear, therefore, that all magnets must possess two poles. As in electricity we call the force which sets the electricity in motion the electro-motive force, so in magnetism, we call the force which sets the magnetic streamings, magnetic flux, or magnetism in motion, the magneto-motive force. This term means magnetism moving force, and is generally contracted M.M.F. We may, therefore, properly regard a magnet not as a source of magnetism, but as a source of magneto-motive force.

Magneto-motive force or M.M.F.

When a bar of hardened steel is being rapidly magnetized and demagnetized, the fact that its molecules resist the motion by which they are aligned or turned in one and the same direction, causes the magnetization of the bar to lag behind the force which produces the magnetization. Consequently, the magnetization of the bar is not reversed at the same time that the magnetizing force reverses or changes its direction. In other words, the magnetizing force may be sending positive flux into the bar, while the magnetism of the bar is still negative. This phenomenon is called magnetic hysteresis, from a Greek verb meaning "to lag behind." It is by reason of hysteresis that rapid changes in the magnetization of a bar of hardened steel are attended by a

Magnetic hysteresis.

small loss of energy, which appears in the steel as heat.

Law of force of magnetic attraction and repulsion.

It can be shown that the force with which two magnet poles attract or repel each other is inversely proportional to the square of the distance between them. If two magnet poles attract each other with a certain force while one inch apart, at one-half this distance apart they will attract each other with a

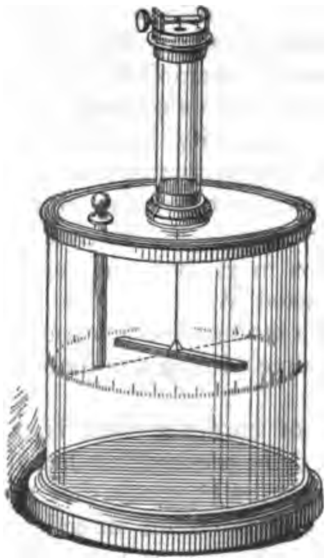


FIG. 95.—Coulomb's Magnetic Torsion Balance. Note the many points of resemblance between this instrument and the electric torsion balance shown in Fig. 10.

Law of inverse squares.

force four times as great; at one-fourth of this distance with a force sixteen times as great, and so on. This law is known as the law of the inverse squares, and is the same law as that which we have seen determines the force with which two bodies containing similar electric charges repel each other.

The application of the law of inverse squares to

magnetic attractions and repulsions was demonstrated by Coulomb by means of an instrument he designed, called the magnetic torsion balance. This instrument, as shown in Fig. 95, resembles both in its construction and method of operation, the torsion balance he invented for measuring the effects of electro-static charges. A long bar magnet, suspended, by means of a thread, in a horizontal position, at the same level as the scale marked on the side of the glass case, takes the place of the shellac needle in the electric torsion balance. The supporting thread is attached to the top of a device for measuring the torsion which the suspended magnet will produce in the thread when it is repelled by the approach of the similar pole of a small magnet introduced through an opening in the top of the cage. This latter magnet corresponds to the proof-plane in the electric torsion balance. As in the case of the electro-static torsion balance, the force with which this repulsion takes place is determined from the amount of the force of torsion produced in the supporting thread.

Coulomb's magnetic torsion balance.

Another method for determining the force of a magnet is to move a magnetic needle slightly out of its position of rest, and then count the number of times the needle swings to-and-fro in a given time—say in a second. It can be shown that the strength of the force possessed by such a magnet pole is proportional to the square of the number of times that the magnet swings to-and-fro in this time. If, for example, of two magnets thus disturbed under similar conditions from a state of rest, one makes twice as many swings as the other in a given time, say one second, then the force that it exerts will be four times as great as the force exerted by the other. Such a method of determining the strength of a magnet pole is called the method of oscillations.

Method of magnetic oscillations.

CHAPTER XVII

PHENOMENA OF THE EARTH'S MAGNETISM

"Magnus magnes ipse est globus terrestris."
—*De Magnete:* GILBERT

THE magnificent generalization made by Gilbert, in his "De Magnete," published in 1590, "Magnus magnes ipse est globus terrestris," or "The earth itself is a great magnet," threw a great flood of light on many of the phenomena of the earth's magnetism. The presence of lodestones, or natural magnets, in the earth, could now be readily explained. If the earth is one huge magnet, then any magnetizable substance on its surface, which possesses the ability of retaining its magnetism when once magnetized, or, in other words, has the power of magnetic retentivity, would be permanently magnetized by mere contact with the earth. The lodestone is an ore consisting of one of the higher oxides of iron; that is, of metallic iron combined in a certain way with the oxygen of the atmosphere. Lodestone can readily become magnetized by being touched by another magnet, and moreover, possesses sufficient hardness to enable it to retain any magnetism it once acquires. Thus, the passage of the earth's flux through a mass of lodestone magnetizes it, and the lodestone is able to retain or keep its magnetism when carried from one place to another. In the same manner, the directive tendency of the magnetic needle is readily explained

Gilbert's splendid magnetic generalization in 1590.

How the lodestone acquires its magnetism.

as being caused by the attractive power of the earth's magnetic poles to the opposite poles of the magnetic needle.

We can now understand the confusion which sometimes arises in the use of the words north and south poles, as applied to those ends of the magnetic needle, which point, respectively, to the geographical north and south. Since it is the opposite poles of magnets that attract each other, if we call the north pole of the needle the end which points to the geographical north, then the Northern Hemisphere of the earth must possess south magnetism. If, on the other hand, we regard the earth's Northern Hemisphere as possessing north magnetism, then it must be the south magnetic pole of the needle that points to the earth's north. It was for this reason that, for a long time, the French called that end of the magnetic needle which points to the north of the earth, the south pole of the needle. Others, to avoid ambiguity, call the pole of the needle which points to the north the north-seeking pole, and the pole which points to the south, the south-seeking pole. Sometimes the term marked pole is employed for the pole that points to the north; while still others sometimes call the pole which points to the north, the red pole of the needle, and that which points to the south the blue pole. Many, however, prefer to call that pole of the magnetic needle which points to the north of the earth, the north pole, and to agree that it possesses north magnetism, and to assume that the Northern Hemisphere of the earth possesses south magnetism. Whatever method is adopted, however, no difficulty will arise if all the facts are borne in mind.

North-seeking and south-seeking magnetic poles.

Marked magnetic poles.

Red and blue magnetic poles.

Were it possible to map out the earth's magnet-

ism, by rendering its flux visible to the human eye, as we have done on a smaller scale in the case of the magnetic figures, by the use of the iron filings thrown on the surface of a photographic plate, we should obtain definite ideas of the earth's magnetism, that would very likely change some of our views concerning it. Supposing, however, things to be in accordance with the present theories, then we would see magnetic streamings, or throbbings in the ether, issue from the earth's north magnetic pole, and, after having traversed the atmosphere, again enter the earth's mass at its south magnetic pole. We would immediately notice, however, that both the number and the general direction of the lines of magnetic force would vary from day to day, from year to year, and through great cycles of time. In other words, the earth undergoes a number of remarkable changes or variations, both in the direction, and in the intensity of its magnetism. In order the more intelligently, therefore, to study the great earth-magnet, we must inquire somewhat particularly into some of these remarkable changes or variations, or, as they are sometimes called, the earth's magnetic elements.

The earth's magnetic field.

The magnetic elements of the earth at any place are three: viz., first, the magnetic intensity, by which is meant the strength of the earth's magnetism at that place; second, the magnetic declination, or the direction in which a magnetic needle, free to move, would come to rest at that place, pointing approximately to the geographic north or south; and third, the magnetic inclination or dip, or the inclined position which a magnetic needle would assume when it comes to rest, provided it were free to move in a vertical as well as in a horizontal, plane. Now, all these magnetic elements of the earth undergo vari-

Magnetic elements of earth.

ations in their value. A study of all the earth's elements will evidently be necessary, since any theory respecting the exact condition of the earth as a magnet must necessarily be able to account not only for each of the elements of its magnetism, but also for any variations that may occur in their value.

Variations in the values of the earth's magnetic elements.

A study of all these elements will be necessary, since any theory respecting the exact condition of the earth as a magnet must necessarily be able to account, not only for each of these elements, but also for any variations that may occur in their value.

Magnetic elements of a place.

The variations that occur in each of the three elements of the earth's magnetism are of four kinds; viz., secular variations, or those occurring during great cycles of time; annual variations, or those occurring during different seasons of the year; diurnal variations, or those occurring during certain hours of the day and night; and irregular variations, or those accompanying magnetic storms or the occurrence of sun-spots. The first three are periodical variations; the fourth is an irregular variation.

Classification of the variations of the earth's magnetism.

As we have seen, the intensity of any magnet varies with the amount of magnetic flux or ether streaming that passes through it. In other words, the magnetic intensity varies with the flux density. Evidently, therefore, the intensity of the earth's magnetism, that is its flux density, varies from day to day, so that the magneto-motive forces which produce the earth's flux must also vary, either in the earth as a whole, or in the amount of the flux that is passing through any particular part of the earth. Since it is the earth's magnetic flux passing through magnetic needles that causes them to point, approximately, to the geographical north, such variations in

Flux density and magnetic intensity.

the intensity of the earth's magnetism can readily be measured, as has been explained, by counting the number of times such a magnetic needle will swing to-and-fro when slightly disturbed from its position of rest.

Coulomb, Humboldt, Hansteen, and Gauss's use of needle of oscillation.

The use of a needle of oscillation to determine the variation in the intensity of the earth's magnetism was first proposed by Graham, a London optician, in 1775. Such a needle was afterward perfected and employed by Coulomb, Humboldt, Hansteen, and Gauss. For example, Humboldt, by this method, determined that the relative magnetic intensity of the earth at Paris was, at the times he made the observations, one and one-third times greater than it was at Peru.

Isodynamic lines and charts.

A careful study in this way gives us a knowledge of the intensity of the earth's magnetism at different parts of its surface. Such differences can be represented by maps or charts on which are drawn lines called isodynamic lines, or lines connecting all places on the earth that have the same magnetic intensity. Such a chart was first proposed by Hansteen, in 1826, and is known as an isodynamic chart.

Importance of accurate knowledge of value of variation in the direction of compass needles.

The variations that occur in the magnetic intensity of the earth are of great scientific value in studying the distribution of its magnetism; but changes that occur in the value of the magnetic declination at different parts of the earth's surface are of greater practical value, on account of the universal employment of the compass needle in navigation. Even comparatively small changes in the direction of a compass needle may readily produce disastrous results if due allowance is not made for

ELECTRICITY AS AN ADJUNCT TO THE TOILET

The upper picture shows the application of facial massage, by means of a rapidly vibrating rubber disk, actuated by an electric motor. In the lower picture an electric fan and heater serve to dry a lady's hair

them, since the false route thus indicated may wreck the vessel.

The variation or declination of the compass needle was known at a very early date by the Chinese. It was also observed both by Columbus and Cabot at a later date. Although since that time an immense amount of information has been obtained by a careful study of the value of the declination at different parts of the earth, even yet the idea exists among many that the magnetic needle invariably points to the true astronomical north at all parts of the earth's surface. Such a belief finds frequent expression in the common phrase, "True as the needle to the pole." Now in point of fact, there are but comparatively few places on the earth where the needle does so point to the north. In all other places it points either to the east or to the west of the north, and in many locations this deviation from the true north reaches a considerable value. The declination or variation of the needle is called east or west according to whether it points to the east or west of the true north.

Early knowledge of the declination of the compass needle.

Popular belief in the invariability of the direction in which the compass needle points.

Lines connecting places on the earth's surface that have the same declination are called isogonal lines, and a chart of the earth on which such lines are drawn, is called an isogonal chart. The line connecting places where there is no declination of the needle; *i.e.*, where the needle points to the true geographical north, is called the Agonal line.

Isogonal lines and charts.

Agonal line.

An isogonal chart of the earth is shown in Fig. 96. In this chart western declination is represented by continuous lines, and eastern declination by dotted lines. The agones are shown by heavy continuous lines. The agone in the Western Hemisphere

Examination of the declination chart.

enters South America near Rio Janeiro, passes the Antilles in a curve, enters the United States and passes near Washington, D. C., crosses to the western part of Hudson Bay and enters the magnetic pole near Boothia Felix. In the Old World it passes through Western Australia, near the western coast of Hindostan, through Persia, the eastern part of the Caspian Sea, and through the White Sea in Europe.

In nearly all Europe, in all of Africa and Arabia, in nearly all the Atlantic and Indian Oceans, and in

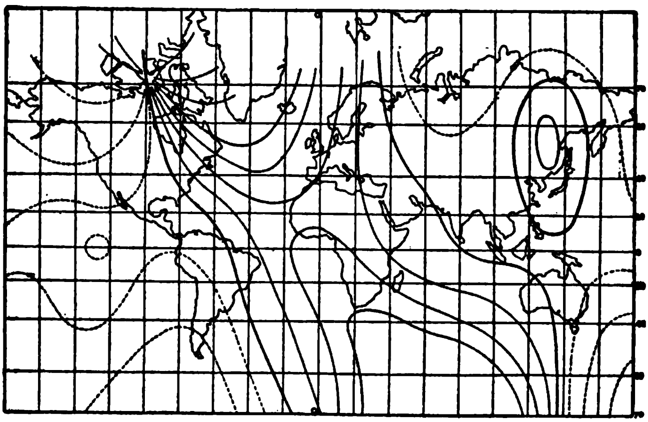


FIG. 96.—Declination Chart. The places where the magnetic needle points to the true north are marked by a heavy line; at all places marked by continuous lines the needle points to the west of the true north, and at all places marked by dotted lines to the east of the north.

the eastern parts of North and South America the declination is west. It is also west in part of Asia, near the secondary magnetic poles.

Halleyan or isogonal lines.

The isogonal lines are sometimes called the Halleyan lines, from Halley, who first prepared maps or

charts on which such lines were marked. The first chart was completed by Halley in the year 1700.

But not only does the magnetic needle fail to point to the true north at different parts of the earth's surface; in addition the value of the declination is not the same at any place, but varies from day to day. Thus, in 1500, the magnetic declination of London was 11° 18′ east. From this time the needle

Secular variation of the declination.

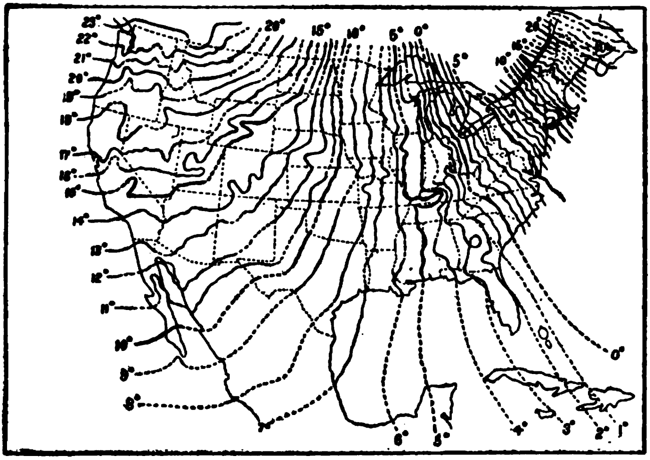


FIG. 97.—Isogonic Chart of the United States for the year 1890.

slowly moved eastward, until in 1662, when it again pointed to the true north. It then began to move toward the west, reaching its greatest western declination of 24° 30′ in 1818. Since this time it has been moving to the east, being in 1901, about 15° 32′ west. This is seen in the isogonal chart of the United States for the year 1890, shown in Fig. 97. Here the agone, or line which marks the places in this country where the needle points to the true geographical north, is seen as passing through South

Comparison of position of isogonal lines in the United States during 1890 and 1900.

Carolina, Ohio, and Michigan. All places east of this line have western declination, and all places west of this line have eastern declination. In the isogonal chart shown in Fig. 98, which is an isogonal chart of the United States for 1900, or ten years later, will be seen the amount of the variation that has occurred in the United States since 1890.

Besides the secular variations in the declination of the needle, there are diurnal or daily variations.

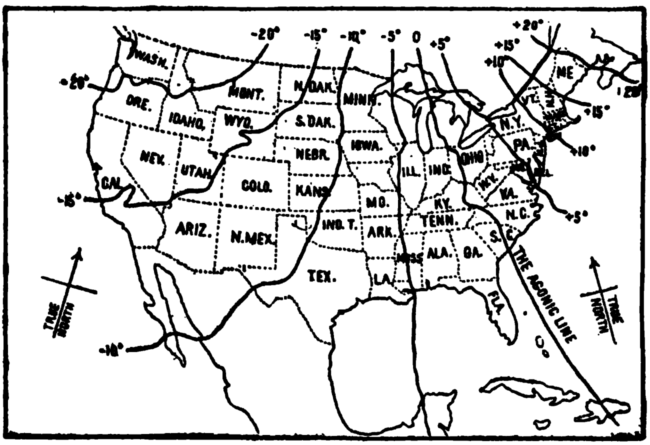


FIG. 98.—Isogonic Chart of the United States for the year 1900.

Graham's observation of the diurnal variation in the declination of the needle at London during 1722.

These were first observed by Graham, in 1722. According to Graham's observations, the north pole of the needle at London, began, between 7 and 8 A.M. to move to the west, and continued this westward motion until 1 P.M., when it became stationary for a few moments. It then began to move slowly to the east until about 10 P.M., when it again came to rest at the point from which it started. A similar oscillation occurred during the night, the north pole

moving west until about 3 A.M., and returning again as before.

The value of the magnetic inclination or dip of the needle varies at different parts of the earth. The value of the magnetic dip at any place is determined by means of the dipping needle. Such a needle is shown in Fig. 99. It consists of a magnetic needle so suspended as to be able to move freely in a vertical as well as in a horizontal direction. In other words, such a needle can both point toward the magnetic north, as well as incline or dip downward toward the earth. The angle of dip or inclination is

Dipping needle.

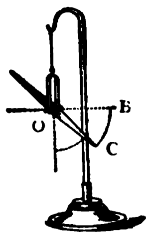


Fig. 99.—Magnetic Dipping Needle. Note that when the angle of dip is 90° the needle would point vertically downward. This would occur directly over the magnetic poles of the earth.

the angular deviation from the horizontal position of the ordinary compass needle. In Fig. 99, the needle shows an angle of dip, BOC, which is the angle between the horizontal line, BO, and the direction, OC, in which the needle dips or inclines.

Where it is desired to make more accurate measurements of the angle of dip, an instrument invented by Biot, called Biot's needle, is employed. Such a device is shown in Fig. 100. With the exception of its magnetic needle and the small spirit level employed to ensure a true horizontal position, the ap-

Biot's dipping circle or needle.

paratus is made entirely of brass. An inspection of the figure shows that the magnetic needle *ab* is suspended so as to move over a vertical graduated circle M, and that this circle is so supported as to be capable of moving over a horizontal graduated circle *m*. In order to read the true angle of dip, the vertical circle is turned until the magnetic needle dips vertically downward, in which position it is exactly 90° from a line passing directly through the magnetic

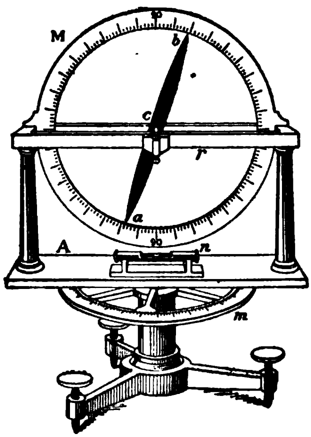


FIG. 100.—Biot's Dipping Needle. The graduated vertical circle marks the angle of dip where the plane in which the needle is free to move is in the plane of the magnetic meridian. The horizontal graduated circle is employed to find the plane of the magnetic meridian.

poles of the earth. The vertical circle is then turned through 90°, so as to bring it in a true north and south line passing through the magnetic poles of the earth, when the needle will incline at its true angle of dip.

Isoclinal lines and charts. Lines connecting places on the earth's surface that have the same inclination, are called isoclinal lines, and a chart or map on which such lines are

drawn is called an isoclinal chart. The line of no dip or inclination corresponds to the position of the magnetic equator. The magnetic equator lies entirely south of the geographical equator. Like the intensity of the earth's magnetism, the value of the dip or inclination is subject to diurnal, annual, and secular variations. Magnetic equator.

CHAPTER XVIII

THEORIES OF THE EARTH'S MAGNETISM

"Not only the greater variations in the earth's magnetism, but the most minute and irregular disturbances occur at the same instant in places the most distant from each other."—*Humboldt's System of Simultaneous Magnetic Observations:* SILLIMAN.

VARIOUS theories have been proposed to account for the earth's magnetism. Among the early philosophers, Descartes, who proposed a vague theory of magnetic vortices, also believed that the earth's magnetism is due to the existence of vast magnetic rocks in the earth. When Norman discovered the dip of the needle in 1580, he clearly showed that the cause of the phenomenon was situated somewhere in the earth below its surface. As we have seen, Gilbert, in 1590, regarded the entire earth as one huge magnet. In order to account for the variations in the needle, Gilbert believed that the earth's magnetism was limited to its solid portions, and that its water was not magnetized; hence, the fact that the needle would be differently affected in different parts of the ocean would be sufficient, he thought, to account for its variation.

Norman on the seat of the earth's magnetism.

Gilbert on the cause of magnetic variation.

In 1673, Bond proposed a theory in which he imagined that the earth's magnetism could be ascribed to a magnetic sphere which encompassed the earth, and revolved around it on an axis that was slightly

Bond's theory for the earth's magnetism.

inclined to the axis of the earth. Bond proposed this theory in order to explain the deviation of the compass, the diurnal variations of which he had discovered in 1650.

In 1692, Halley proposed a theory, in which, like Gilbert, he supposed the earth was a magnet, but declared that it had four instead of two magnetic poles. These magnetic poles were assumed to be caused by two magnetic shells, of which he conceived the earth to be composed. One of these, an outer shell, produced two of the earth's poles, and the other, an inner shell, the remaining two. Halley explained the variations of the magnetic needle by supposing that these shells revolved around their axes at different rates.

Halley on the earth's magnetism.

In 1757, Euler proposed a theory, in which, like Gilbert, he asserted that the phenomena of the earth's magnetism could be explained by the existence of only two poles, which, however, are not directly opposite each other. In other words, the poles are so placed that a straight line joining them would not pass through the centre of the earth. Euler endeavored to show that it would be possible to give these two poles such positions and values as to produce variations in the needle similar to those of the isogonal lines. Indeed, he even goes so far as to assert that having once determined the position of the two poles, the directions of the isogonal lines could be determined with the same readiness and accuracy as a proposition in geometry.

Euler's geometrical basis of the variation of the earth's magnetism.

In 1805, Biot proposed a theory in which he supposed the magnetism of the earth to be due to the presence of a single magnet of short length, located somewhere near the centre of the earth. He im-

Biot's theory of the earth's magnetism.

agined that the poles of this magnet were placed near each other. Biot believed that he was able to prove, from mathematical calculations, that all the phenomena of the earth's magnetism could be explained in this manner. But Pouillet, in the light of subsequent knowledge, denies the correctness of Biot's theory.

Hansteen's theory of the earth's magnetism.

In 1811, the Royal Danish Academy offered a prize for the best solution of the cause of the variation of the compass needle. Hansteen undertook this solution, and won the prize in 1819, when he proposed a theory of magnetism based on Halley's theory, and like it, calling for the existence of four separate magnet poles. Hansteen showed, however, that it would be necessary to suppose these poles were each of different magnetic force, and that each pole was constantly changing its position at its own rate of motion. Hansteen assumed that the focus, or seat of the earth's magnetism, was situated somewhere near the earth's centre, but that it manifested itself mainly at four points or poles near the surface. Two of these poles, situated at the extremities of the magnetic axis, were the principal magnetic poles of the earth. The other two, the secondary poles, had an independent axis of their own on which they moved from west to east around the principal poles.

Barlow's theory of the earth's magnetism.

In 1817, Barlow formed a theory of the earth's magnetism, in which he claimed that neither the presence of a single magnet in the earth nor the presence of several magnets could properly explain the phenomena of the earth's magnetism. He asserted that each region of the earth has its own poles, that such poles change their position by a revolution produced by some unknown cause.

In 1835, Gauss proposed a theory, in which, like Barlow, he claims that although the earth like a single magnet has two poles only, yet, as Sir William Snow Harris, to whom we are indebted for many of the facts of this early history of the earth's magnetism, says: Gauss' theory of the earth's magnetism.

"That the earth does not contain a single definite magnet, but irregularly diffused magnetic elements, having collectively a distant resemblance to the condition of a common magnet. So that for magnetic poles we must substitute magnetic regions, over which a general magnetic influence obtains. Thus, instead of a Siberian pole, as determined by Hansteen, we have a Siberian region, in which the isogonal lines may be conceived to converge without coming absolutely to a point." Harris on the cause of the earth's magnetism.

A later theory of the earth's magnetism has been founded upon two discoveries, the principles of which we have not yet discussed. These are the discovery, by Oersted, in 1820, of the production of magnetism by electric currents, and the discovery, in 1822, by Seebeck, of the production of thermo-electricity, by differences of temperature. These two great facts were combined in a theory for the earth's magnetism by Grover, in 1849, who proposed the theory which is, perhaps, more generally credited at the present time, at least in some of its details, than any other. This theory affirms that the magnetism of the earth may be ascribed to the presence of electrical currents circulating around it from west to east. Discoveries of Oersted and Seebeck combined in a theory of the earth's magnetism by Grover.

The preceding are but some of the more important theories that have been proposed by scientific men to account for the magnetism of the earth. No matter what theory may be held, it is certain, as a re- Causes producing the earth's magnetism act on the earth as a single body.

sult of a wonderful generalization, reached by Alexander von Humboldt by means of a movement he inaugurated in 1836, that whatever be the cause of the earth's magnetism, this cause acts on the earth as a whole. This generalization is so justly to be regarded as, perhaps, the most wonderful ever made in the history of magnetism, that we will explain it in some detail.

Wonderful generalization of Humboldt revealed by simultaneous observations undertaken at different parts of the world in 1836.

In 1836, Humboldt proposed both to the leading governments of the civilized world, and to most of the scientific societies, in both the New and the Old World, that a series of connected and simultaneous observations be made over as large a part of the earth as possible, in order to determine the laws governing the distribution of the earth's magnetism. In accordance with this suggestion, magnetic observatories were established both on and below the surface of the earth. In these observatories delicate magnetic instruments were placed especially devised for the purpose. In order to avoid the disturbing effect of neighboring magnets, the observatories were constructed entirely of non-magnetic materials. These observatories were located not only in civilized portions of the world, but were also erected by special expeditions in Africa, North and South America, India, Russia, the Pacific Ocean, and within the Arctic and the Antarctic circles. In this way an immense mass of important facts was obtained concerning the earth's magnetism.

Magnetic changes occurring at any part of the earth instantaneously followed by corresponding changes at all other parts of the earth.

"But perhaps the most remarkable results thus obtained," says Silliman, from whom we have condensed the above statement, "is the fact first established by them, that not only the greater variations in the earth's magnetism, but the most minute and irregular disturbances, occur at the same instant in places the most distant from each other, showing the

wonderful connection and coincidence in the causes of these phenomena throughout the world."

In 1840, the British Government, in co-operation with the East India Company, greatly extended this system of simultaneous magnetic observations, and obtained similar results; viz., that variations in the magnetic intensity, declination, and dip, occur simultaneously in all parts of the earth. In other words, both of these sets of observations showed that there occurred on the earth what may be called true magnetic storms, during which all the magnetic elements of the earth exhibited, at all parts of its surface, simultaneous and marked fluctuations.

Simultaneous observations of the British Government and the East India Company in 1840.

From the knowledge we have of the earth's magnetism to-day, it would appear that the seat of this force lies in the crust rather than somewhere near the earth's centre; and, that in some way or other, the causes of the magneto-motive forces that produce the earth's magnetism are to be traced to the sun. Such a theory, it would appear, traces the diurnal, annual, and secular changes or variations to variations in temperature during every twenty-four hours, every year, or during long cycles or periods of time. This belief has been strengthened by the fact that the isoclinal lines, or lines of equal inclination or dip of the needle, extend in almost the same direction with the isothermal lines, or lines connecting places on the earth's surface which have the same average annual temperature.

Close correspondence of the isoclinal and the isothermal lines.

It has been frequently suggested that the earth's magnetism can be traced either directly or indirectly to the sun. That the sun is a body possessing powerful electric and magnetic forces is acknowledged by all. Might it not, it has, therefore, been asked,

Is the sun the main source of the earth's magnetism?

produce all the magnetic phenomena of the earth by simple induction?

Occurrence of sun-spots and magnetic storms.

As we have already seen, the aurora, which undoubtedly appear to be both magnetic and electric phenomena, are either accompanied or preceded by those unusual outbursts of solar activity that are called sun-spots. The appearance of sun-spots seems to be due to some unusual activity in the sun. The visible portion of the sun's surface is called the

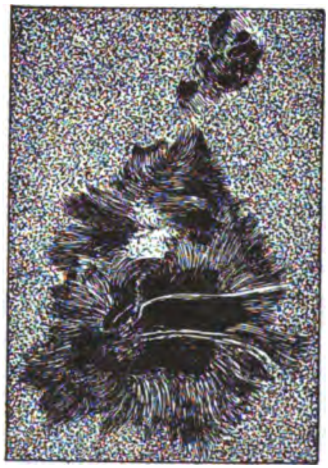


FIG. 101.—Great Sun Spot of September, 1870, from drawing by Langley.

photosphere. When studied under favorable conditions, with a properly screened glass, the sun's surface does not appear to be smooth and bright, but is rough or mottled, or, as Young expresses it, "somewhat resembling rough drawing-paper." With a powerful glass, under good conditions of the atmosphere, the surface is seen sprinkled with granules or nodules scattered over a dark background. These are believed to be luminous clouds, which are float-

ing in the less luminous atmosphere of the sun. Sun-spots appear as dark regions on the sun's surface, dark, however, only by contrast with the surrounding brighter portions. They are now practically known to be due to cavities in the photosphere. The dark appearance is due to the lower temperature of the mass of gases and vapors with which they are filled.

The appearance of an unusually great sun-spot, which was observed during the month of September,

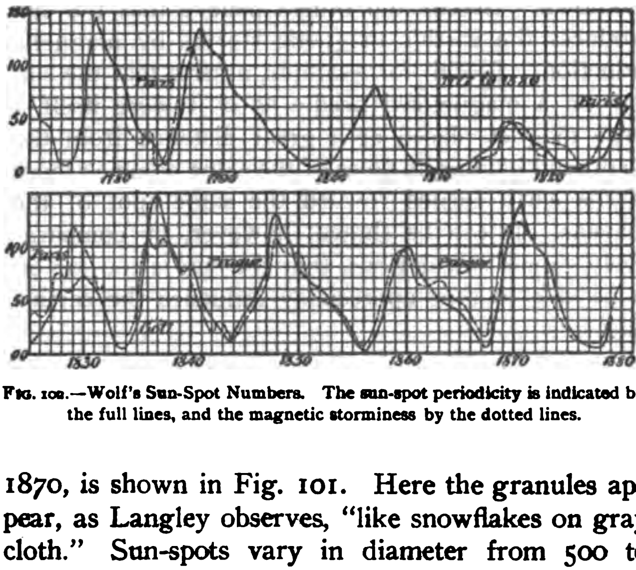


Fig. 100.—Wolf's Sun-Spot Numbers. The sun-spot periodicity is indicated by the full lines, and the magnetic storminess by the dotted lines.

Great sun-spot of September, 1870.

1870, is shown in Fig. 101. Here the granules appear, as Langley observes, "like snowflakes on gray cloth." Sun-spots vary in diameter from 500 to 50,000 miles. The dark region surrounding a number of separate sun-spots sometimes reaches the enormous dimension of 150,000 miles in diameter!

Wolf's sun-spot numbers.

The fact that the appearance of sun-spots is invariably followed by magnetic storms on the earth has been demonstrated by Wolf, through a com-

parison of observations of sun-spots and magnetic storms between 1772 and 1880. The result of Wolf's observations is shown in Fig. 102. Here the full lines mark the occurrence of the sun-spots, while the dotted lines show the occurrence of magnetic storms. The numbers from 0 to 150, marked on the left-hand side of the figures, indicate the number of sun-spots that occur during any year, while the years of the occurrence are placed in numbers at the bottom of the figures. While, however, the fact of such connection is shown, neither the exact nature of the phenomenon, nor the manner in which it acts, is known. Secchi and others believe that the sun produces the earth's magnetic storms by magnetic induction. Secchi, for example, asserts that the sun acts on a magnetized needle as if it were itself a large magnet placed at a great distance from the earth, and having its poles of the same name as those of the earth turned toward the same spot of the heavens. It can be shown, however, by comparatively simple calculations, that the sun is too far off to be able to thus appreciably influence the earth's magnetism.

Secchi on the sun as the direct cause of the earth's magnetism.

Others believe, as has already been explained, that the sun acts by means of thermo-electric currents, produced in the materials of the crust by differences of temperature caused by the sun's heat. If we imagine such currents as flowing through the materials of the crust from west to east, it can be shown that the earth would have magnetic poles corresponding fairly closely to its actual poles. It has, however, been very properly objected to this theory that a large part of the earth's surface is covered with water, and that, so far as is now known, such currents can not be produced in liquids by differences of temperature.

Objection to thermo-electric theory of earth's magnetism.

De la Rive modifies the above theory by the suggestion that at least a part of the phenomena of the earth's magnetism can be explained by means of electric currents, which, as we have already pointed out in connection with the cause of auroras, he believes circulate around the earth between the equator and the poles. These currents result from the evaporation of vapor from the ocean as it is carried by the winds in their movements to and from the equator and the poles.

De la Rive's theory of the earth's magnetism.

Faraday suggests that the sun's heat may produce the variations in the earth's magnetism in an entirely different manner. He discovered, during certain investigations to which we shall soon refer, that the oxygen of the atmosphere is naturally magnetic, and that this magnetism increases in amount as the air grows colder, and decreases in amount as it grows warmer. He believes, therefore, that it is by variations in the temperature of the air during different parts of the day, year, or cycle of time, that the variations of the magnetic needle are caused.

Faraday's theory of the earth's magnetism.

It may be well to give here a quotation from an address by Kelvin, on these subjects, delivered prior to 1879, as showing the opinions then generally held:

"As to terrestrial magnetism, of what its relation may be to perceptible electric manifestations we at present know nothing. You all know that the earth acts as a great magnet. Dr. Gilbert, of Colchester, made that clear nearly 300 years ago; but how the earth acts as a great magnet—how it is a magnet—whether an electro-magnet in virtue of currents revolving round under the upper surface, or whether it is a magnet like a mass of steel or lodestone, we do not know.

Kelvin on the causes and phenomena of the earth's magnetism.

. . . .

"What are called 'magnetic storms' are of not

very unfrequent occurrence. In a magnetic storm the needle will often fly twenty minutes, thirty minutes, a degree, or even as much as two or three degrees sometimes, from its proper position—if I may use that term—its proper position for the time: that is, the position which it might be expected to have at the time according to the statistics of previous observations. I speak of the needle in general. The ordinary observation of the horizontal needle shows these phenomena. So does observation on the dip of the needle. So does observation on the total intensity of the terrestrial magnetic force. The three elements, deflection, dip, and total intensity, all vary every day with the ordinary diurnal variation, and irregularly with the magnetic storm. The magnetic storm is always associated with a visible phenomenon, which we call, habitually, electrical; aurora borealis, and, no doubt, also the aurora of the southern polar regions.

Magnetic storms.

"We have the strongest possible reasons for believing that the aurora consists of electric currents, like the electric phenomena presented by currents of electricity through what are called vacuum tubes, through the space occupied by vacuums of different qualities in the well-known vacuum tubes. Of course the very expression, 'vacuums of different qualities,' is a contradiction in terms. It implies that there are small quantities of matter of different kinds left in those nearest approaches to a perfect vacuum which we can make.

Auroral phenomena and electric currents.

. . . .

"Now, if we could have simultaneous observations of the underground currents, of the three magnetic elements, and of the aurora, we should have a mass of evidence from which, I believe, without fail, we ought to be able to conclude an answer more or less definite to the question I have put. Are we to look

in the regions external to our atmosphere for the cause of the underground currents, or are we to look under the earth for some unknown cause affecting terrestrial magnetism and giving rise to an induction of those currents? The direction of the effects, if we can only observe those directions, will help us most materially to judge as to what answer should be given."

The earth, then, being assumed to be a great magnet, it is easy to account for the phenomena of magnetic dip or inclination. Let us suppose, as in Fig.

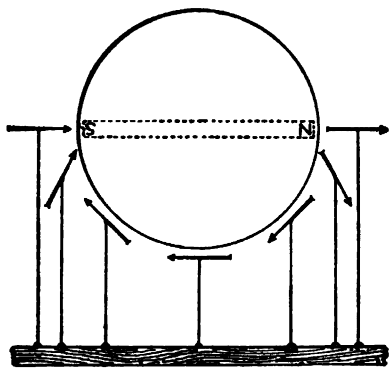


FIG. 103.—Cause of the inclination or dip of the magnetic needle.

103, that the earth's magnetism is due to say a single magnet, whose poles are situated at the points N and S, respectively, and that dipping needles be supported over different parts of its surface, as shown, the north pole of the needle being indicated by the point of the arrow, it is easy to see that such needles would come to rest in different positions with their north poles pointing in the different directions shown, and that such directions would correspond, approximately, to the angle of magnetic dip in different parts of the world.

Cause of the dip or inclination of the magnetic needle.

Magnetic divining rod.

Attempts have been made to locate the presence of large bodies of iron ore below the earth's surface by a small magnet employed as a kind of magnetic divining rod. The use of such an instrument does not, however, appear to have been successful, owing, most probably, to the fact that comparatively small quantities of iron ore near the surface would affect such an instrument as powerfully as much larger bodies some little distance below the surface.

Some resemblances between magnetic flux and X- and Becquerel rays.

The ability of the X-rays, Becquerel rays, and other rays, to readily pass through matter that is opaque to ordinary light, has already been referred to. Magnetic flux also possesses this ability, to at least as marked a degree. As we have seen, magnetic induction can take place through media opaque to light, such as blackened glass, china, wood, a number of pages of an ordinary book, and the human body. Magnetic emanations or flux differ, however, from the above-mentioned rays, in that, so far as is known, the magnetic rays are unable to affect a photographic plate like the other rays. It is true that Reichenbach, in 1844, asserts that there are people peculiarly sensitive to magnetic influences, who, in a perfectly dark room, can see the emanations at the poles of a magnet (*i.e.*, magnetic flux) as faint luminous rays of various colors. He claims, moreover, that photographic pictures can be obtained on plates of the character employed by Daguerre; thus showing that such emanations were actual and not imaginary. It does not appear, however, on trial, that this latter statement is borne out by fact, either in the case of Daguerre's sensitive plates, or in the still more sensitive photographic dry plates that are employed to-day.

Reichenbach and the luminous emanations from magnetic poles.

CHAPTER XIX

THE MARINER'S COMPASS

"Such an invention as this, so sound in principle, so easy in application, and so universally beneficial in practice, needs no testimony of mine to establish its merits; but when I consider the many anxious days and sleepless nights which the uselessness of the compass in these seas had formerly occasioned me, I really should have esteemed it a kind of ingratitude to Mr. Barlow, as well as great injustice to so memorable a discovery, not to have stated my opinion of its merits, under circumstances so well calculated to put them to a satisfactory trial."—CAPTAIN PARRY on *Barlow's Soft Iron Globe*

IT is an interesting fact, that the mysterious power of the magnetic needle to point, approximately, to the geographical north, was employed to guide vessels on the ocean when clouds so obscured the sun or other heavenly bodies, for days at a time, as to render them useless for obtaining general directions, many years before our knowledge of the laws by which the movements of the needle were governed—even, in point of fact, before any knowledge was had at all of the nature of the magnetic force itself.

Compass used before its users knew what magnetism was.

There are two things that a navigator must know in steering his vessel; viz., the direction in which he is sailing, and the distance he has passed over in any given time. The first is determined, either by an observation of a star or other heavenly body, or by the compass needle; the second can readily be obtained by reckoning his position astronomically by

How a navigator determines his position.

How a navigator determines the distance his ship has gone.

means of a comparison of the time of noon, or, when the sun appears directly overhead, with that kept by an accurate timepiece, called a chronometer. This time, after the proper correction is made for the error of the chronometer, gives the time of noon at Greenwich. The distance he has passed through may also be determined by an instrument called a

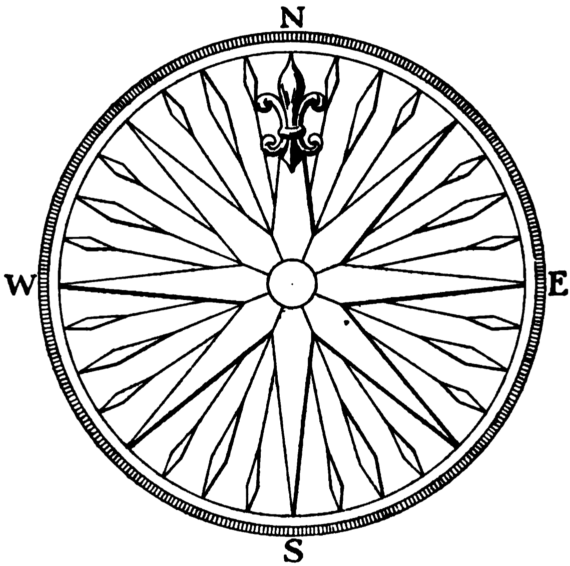


FIG. 104.—Compass Card. Here the thirty-two rhumbs or points are shown, but the names are attached to only a few of them.

log, which gives the rate at which the ship is moving at the time when the observation is made.

What the compass tells the navigator.

What a navigator sees in the ship's compass is the direction in which the ship is sailing. This direction is reckoned as being so many degrees to the east or to the west of a line, or more properly a great circle, passing through the north and south magnetic poles of the earth, and near the magnetic meridian.

In the magnetic compass, as used to-day, the magnetic needle is fixed to the lower surface of a card, called the compass card. The face of the compass card is marked with the four cardinal points, N., S., E., and W., and these are divided into 32 points called rhumbs of the compass. A compass card so divided is shown in Fig. 104. Here it will be

Compass card.

Rhumbs of the compass

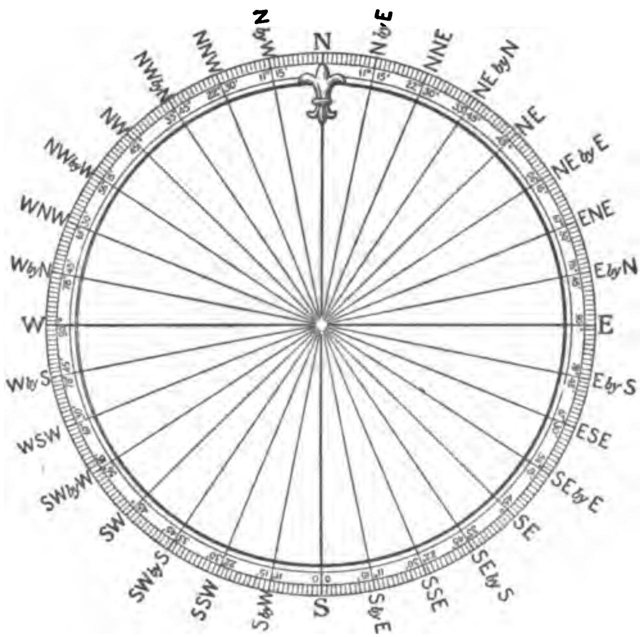


FIG. 105.—Compass Card. Compare this with Fig 139, and note the names of the 32 rhumbs, as well as their values in degrees and minutes of circular measure.

seen that the point midway between N. and E. is called N. E.; the point midway between N. and N. E. is called N. N. E., and the point midway between N. E. and E. is called E. N. E., and so on. The naming from memory of the thirty-two successive points, so obtained, is what the sailors call "Boxing the compass." These points named in suc-

Boxing the compass.

cessive order from north around the entire circle to the point of beginning, are as follows:

The compass boxed.

N.	E.	S.	W.
N. by E.	E. by S.	S. by W.	W. by N.
N. N. E.	E. S. E.	S. S. W.	W. N. W.
N. E. by N.	S. E. by E.	S. W. by S.	N. W. by W.
N. E.	S. E.	S. W.	N. W.
N. E. by E.	S. E. by S.	S. W. by W.	N. W. by N.
E. N. E.	S. S. E.	W. S. W.	N. N. W.
E. by N.	S. by E.	W. by S.	N. by W.

It has been found, however, in modern navigation, preferable to divide the compass card into de-

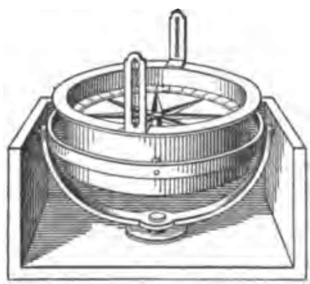


FIG. 106.—The Mariner's Compass. Note here the position of the pivotal points of the concentric brass circles or gimbals.

Compass card divided into degrees.

grees and minutes of the circle, as shown in Fig. 105, so that instead of reading any point, as for example, the point E. N. E., we read N. 67° 30′ E., and so on.

Common form of mariner's compass.

The mariner's compass is made in a variety of forms. One of the most convenient is that shown in Fig. 106. Here the compass card is placed inside a box of glass, wood, or other non-magnetic material, called the compass box. This box is loaded with a mass of lead, in order to increase its stability.

It must be borne in mind that, in the mariner's compass, unlike in the ordinary compass employed

ELECTRIC HAULAGE IN MINES

The amount of time and labor saved in mining operations by the substitution of electricity for hand and mule power is one of the wonders of the day. In many mines all hauling is now done by electric locomotives

for showing directions on land, a fixed compass card, with a magnetic needle moving over the card, would not be practicable on board ship, since the vessel is constantly changing its direction, and rocking and pitching to-and-fro. It is necessary, therefore, to attach the compass needle to the card, and so support the card on a pivot, that both the card and the needle may move together. As before mentioned, the needle is fixed to the lower face of the card, with its north and south points immediately below the north and south points of the compass card. Consequently, all the points on the card will be correctly placed in reference to the magnetic meridian of the place, no matter how the ship may turn.

Why in the mariner's compass the compass card and needle must move together.

In order to prevent the pitching and rolling of the ship from interfering with the direction of the needle, the compass box is suspended in a box on two concentric brass circles called gimbals, the horizontal pivots or axes of which are at right angles to each other, as seen from an inspection of the figure. As a result of this method of support, the compass box will remain in a horizontal position during the motions to which the vessel is subjected. The box inside of which the compass is placed, is called the binnacle. The binnacle box is placed where it can readily be seen by the man at the wheel. The binnacle box is provided with a lamp, so as to permit the compass to be read at night. Sights are provided at G and H, in such a position that the line of sight passes directly over the centre of the compass card.

Gimbals.

The binnacle.

In its earliest form, the magnetic needle in the mariner's compass consisted of a common sewing needle, which, after being magnetized, was passed through a piece of cork and allowed to float on a water surface. The length of the needle was subse-

Earliest form of compass needle.

quently increased to six inches or longer, the needle being suspended in a china bowl filled with water. According to Harris, the present form of compass is of a comparatively recent date. Indeed, ship's compasses have been greatly improved since 1820; for, Barlow, who was at that time commissioned by the Board of Admiralty of England to investigate and report on the actual conditions of ship's compasses then employed in the Royal Navy, informed the Government "That at least one-half of them were mere lumber, and ought to be destroyed."

Barlow on the inefficiency of compass needles prior to 1820.

In 1750, Dr. Gowan Knight called attention to a source of error in a ship's compass, arising from defects in the construction of the magnetic needle. At this time compass needles were formed of two pieces of steel, open in the middle, and united in the form of a lozenge or rhombus. An examination of some twenty of such needles showed that all possessed marked variations from the direction in which a properly constructed needle should point. This was caused by differences existing in the temper of the steel at different parts of the needles, the hardest side of the lozenge-shaped needle possessing the greatest directing power. In other words, the construction of the needle resulted in its north and south poles not coinciding with the extremities of the lozenge-shaped needle, and thus the indications of the needle would necessarily be false. Knight called attention to the fact that while a magnetic needle consisting of a piece of tempered steel, pointed at its ends, and containing less metal near the central parts than toward the ends, was better than the lozenge-shaped needle, yet such a needle was objectionable, since it might acquire six poles, as might be shown by rolling the needle in iron filings. After a careful study of the problem Knight recommended the adop-

The inaccuracy and unreliability of lozenge-shaped magnetic needles.

tion of needles made from straight, narrow steel bars, as giving the best results, and such needles are practically the shape of the needles employed in the mariner's compass of to-day. Straight bar compass needles preferable.

The use of several separate magnets on the same compass card is now employed in Kelvin's modern ship's compass. Here eight separate short steel wires, strongly magnetized, and suspended side by side by threads, are attached to the compass card. This use of a number of separate magnets extended back nearly ninety years. Kelvin's compass needles.

It is interesting, in this connection, to note the views held as to the proper construction of compass needles as early as 1795, by Cavallo in his book on "Electricity," before alluded to:

"Compasses for the sea service formerly, and some even at present, are made in the following improper manner: The brass cap is fastened to the middle of a circular card, upon which the various points of the horizon, as the east, west, etc., are marked. On the under part, two pieces of magnetic steel are stuck fast to it, so as to be parallel, and to stand about half an inch distant from one another, the pin upon which the whole is suspended passing between them." Cavallo on ship's compasses.

Harris, to whom we have already referred, in connection with the electrical protection of ships by means of lightning rods, constructed a ship's compass, which was very generally employed both by the English Government, and by the East India Company. In this compass the magnetic needle was in the shape of a light, straight bar, from five to seven inches in length, mounted on an agate centre. The needle was provided with two small silver riders, Harris's great improvements on ship's compasses.

placed at equal distances from the ends of the bar, hardened, tempered, and balanced on its support before being magnetized. When the needle was magnetized its tendency to dip or incline to the earth was balanced by moving one of the silver riders in the proper direction. Since the magnetic dip or inclination varies in different parts of the earth, the horizontal position of the needle requires an adjustment of the rider whenever either end shows a tendency to incline. This method was adopted in order to lessen the tendency of the needle to oscillate or swing. The magnetism of the needle employed in Harris's compass was sufficiently strong to enable it to lift a load three times its own weight.

Magnetic needle supported at true centre of the needle, and tendency to dip or incline balanced by movable riders.

Harris made an improvement in his compass by means of which he prevented the needle from continuing its oscillations to-and-fro, and thus causing it to come quickly to rest in its true pointing position. This he obtained by means of a heavy ring of copper, placed near the outer edge of the compass card. The ability of such a metallic ring to deaden or stop a rapidly moving magnetic needle, near which it is placed, is due to electrical currents induced in the copper ring by the movements of the magnetic needle, in a manner that we shall subsequently discuss. The supporting point, on which the needle rested, was made in two pieces in order to enable it rapidly to be unscrewed from its support, reversed, and again placed in position. By these means the supporting point could be readily replaced in case of injury or marked wear.

Copper ring to rapidly check oscillations of compass needle.

It would seem to be quite a simple matter to obtain the true course of a ship by means of the mariner's compass, since, apparently, it is only necessary that one observe the direction in which the needle points.

This, however, is far from being the case. In the first place, when the direction of the needle is ascertained, it is necessary to make a correction for the declination or variation at the place in which the ship may then happen to be. But even when such a correction is made the precautions are only partly taken. There are other variations of the needle, of a local character, that are far more difficult to correct. Such are the deviations produced by masses of iron in the ship, such as are found in wooden ships, in its guns, anchors, cables, etc. The disturbances thus caused, in some cases, produce variations amounting to as much as 15° or 20°.

Difficulties in determining true directions from a ship's compass.

But if such marked deflections occur in wooden ships, what must they be in ships made entirely of steel? Here the necessity for correction is greatly increased. This difficulty will, perhaps, be better understood when it is remembered that the masses of iron and steel in a ship become magnetized, by induction from the earth, in a direction parallel to the dip of the needle, and with a magnetic intensity proportional to the intensity of the earth's magnetism at that place. Now such masses, when of hardened steel, become permanently magnetized, and when of soft iron, only temporarily magnetized. When, therefore, the ship crosses the Magnetic Equator of the earth, all the poles of the temporary magnets are instantly reversed, while the poles of the permanent magnets are either not reversed at all, or only change their direction after comparatively long periods of time.

Increase of amount of local variation in iron and steel ships.

The following account of the loss of an iron ship, resulting from a false course, due to local variations of the compass needle, is thus given in a report made at the twenty-fourth meeting of the British Association, at Liverpool:

"A most lamentable instance of the loss of an iron ship in consequence of changes in the action of her compasses, occurred in the early part of the year 1854. The circumstances were as follows: The ship, *Tayleur,* a new vessel bound to Australia, sailed from Liverpool on Thursday, 19th January; she was 1,979 tons burden, new measurement, and she had on board 458 passengers—the crew and passengers together making a total of 528 persons. She left the Mersey about noon, and the pilot left her between seven and eight o'clock in the evening in a position between Point Lynas and the Skerries. On Friday she encountered very heavy weather, and about eight o'clock on the following morning it was for the first time ascertained that there was any material difference between her compasses. One was near the helmsman, and was the one by which he was steering; the other was near the mizzen mast. Both of these compasses had been adjusted by permanent magnets, so that if the principle of adjustment had been correct, they should not either have changed or differed from each other. Trusting to the compass near the helmsman, the captain had the idea firmly impressed upon his mind that he was sailing fairly down almost mid-channel; at all events, in a good position for navigating the Irish channel. The other compass indicated a difference of about two points; the captain, however, judging from certain indications which he had noticed previously, assumed that the wheel compass was the correct one. In the course of a few hours—about half-past eleven o'clock on the same morning—the wind having increased and a heavy sea setting up the channel, the ship made rather a rapid progress, when they came suddenly in sight of land on the lee beam in such a position that there was necessarily a great difficulty—in this case (according to the measures pursued), an in-

Total loss of the *Tayleur* off Lambay Island in 1854, by local variation of ship's compass.

surmountable difficulty—in avoiding the land. An attempt was made to wear the ship round; this failed, and then an attempt was made to use the anchors to bring her up. Both the cables snapped on the occasion, and the ship was thus left helpless, driving broadside upon the rocks of Lambay Island. The result was the fearful catastrophe of the loss of about 290 lives! Inquiries were instituted by the Board of Trade in two departments; one by means of Captain Walker, of the Navy, who ascribed the loss of the vessel to the captain's supposition that the compass by the helm was correct; the other by means of the Marine Board of Liverpool, who reported that although the captain had given very great attention to the ascertaining of the correctness of his compasses, yet the *Tayleur* was brought into the dangerous position in which the wreck took place, through the deviation of the compasses—the cause of which, they (the Marine Board) had been unable to determine."

Too late to wear the ship.

Various devices have been employed for the purpose of correcting the local deflections in the ship's compass needle. Barlow, in 1818, made an extended examination of the local variation of the ship's compass, arising from the masses of iron in its guns. In the course of this investigation, he found that globes of soft iron, shaped like bomb-shells, one foot or more in diameter, acted like miniature copies of the earth, by reason of the inductive action which the earth's magnetism exerted on them. These globes, having their magnetic axes in the line of the dip, and their equator at right angles to their axes, would prevent a delicate magnetic needle, when supported on their equatorial line, from being disturbed by the magnetism of surrounding bodies. Therefore, such a globe of iron,

Barlow's valuable discovery of quadrantal compensating globes of soft iron.

placed in a certain relation to the ship's compass, would shield it from disturbance by outside magnetic forces.

General use of Barlow's invention.

Barlow's device was introduced into the Royal Navy, and was soon adopted by all the navies of the world. Even in regions like those near the magnetic poles of the earth, where ordinary magnets are practically valueless, compasses so protected have been found able to indicate the true magnetic direction.

Prize and gift for Barlow.

The Board of Longitude awarded to Mr. Barlow, for this valuable invention, a prize of £500, while the Emperor of Russia presented him with a fine watch and chain.

Additional use of permanent magnets.

Attempts have been made to overcome local attraction by means of permanent magnets placed in various positions around the ship's compass. The method generally adopted at the present time, as affording the best protection, is to employ Barlow's globes for variations due to masses of soft iron in the ship, and permanent magnets for those due to the magnetized masses of hardened iron and steel.

Before leaving this subject, it may be well to inquire briefly into the character of the errors that occur in the direction of a ship's compass by the magnetism of the ship. It is evident that the amount of this local deflection of the needle must necessarily vary according to the character of the magnetization of the ship when the ship is sailing in different directions, the amount being one thing when the ship is sailing in the direction of the magnetic meridian, and quite another thing when it is sailing in a direction at right angles thereto.

Such errors can be arranged generally under three heads: viz., the semicircular error, the quadrantal error, and the heeling error. The semicircular error is that caused by the permanent magnetism of the ship considered as a steel bar magnet. This error is called semicircular because it causes an easterly

Semi-circular error.

FIG. 107.—Kelvin's Compensating Binnacle. The Barlow quadrantal correctors are seen to the right and left of the compass in the shape of two spheres of soft iron.

deviation of the compass needle while the ship is turning through one-half circle, and a westerly deviation while the ship is turning through the remaining half-circle. The quadrantal error is the error due to the induced magnetism of the ship's iron considered as a mass of soft iron. Such a magnetization changes when the ship crosses the Magnetic

Quadrantal error.

Equator. It is called the quadrantal error because the deviation is easterly during two quadrants or quarter circles, and westerly during the remaining alternating quadrants. The heeling error is that caused by both the permanent and temporary magnetism of the ship acting in a vertical plane, and

Heeling error.

FIG. 108.—Riggs' Compensating Binnacle for Pilot House or Deck. Besides the Barlow quadrantal corrector, the open door of the box shows the correcting magnets.

which, therefore, only acts when the ship is pitching or "heeling over."

Kelvin's ship's compass.

A form of modern ship's compass mounted in a binnacle box, is shown in Fig. 107. This is the form devised by Kelvin. The compass needle consists of six slender rods of hardened steel, placed

under the surface of the compass card. The Barlow soft-iron globes, called the quadrantal compensators, are placed as shown on each side of the compass box beneath the compass case, and inside the support on which the box rests are placed permanent magnets of hardened steel, in such positions as to best compensate for the semicircular error. Another permanent magnet is placed so as to compensate for the heeling error. In order to check the oscillations of the compass needle, the needle is surrounded by some viscid liquid, such as oil or glycerine.

A form of compensating binnacle, known as the Riggs' compensating binnacle, is shown in Fig. 108. Here besides the Barlow quadrantal compensators, can be seen through the open door of the case some of the correcting magnets.

Riggs' compensating binnacle.

CHAPTER XX

ACTION OF MAGNETISM ON ALL BODIES

"Of the substances which compose the crust of the earth, by far the greater portion belongs to the diamagnetic class; and though ferruginous and other magnetic matters, being more energetic in their action, are consequently more striking in their phænomena, we should be hasty in assuming that therefore they overrule entirely the effect of the former bodies. As regards the ocean, lakes, rivers, and the atmosphere, they will exert their peculiar effect almost uninfluenced by any magnetic matter in them; and as respects the rocks and mountains, their diamagnetic influence is perhaps greater than might be anticipated."—*Experimental Researches in Electricity,* 2448: MICHAEL FARADAY

IN early times it was believed that comparatively few metals besides iron and steel possessed the power of acquiring magnetism. Indeed, even at the present time, it is quite common to call certain metals, such as iron, nickel, manganese, cobalt, chromium and cerium, the magnetic metals, as we have already done in a prior chapter. In fact, however, there are practically no substances that are not affected, at least to some small degree, by the action of powerful magnetic flux. Since the extent to which these substances are affected is quite small, no serious difficulty arises from calling the before-mentioned metallic substances the magnetic metals. It is exceedingly important, however, that we study somewhat more in detail the manner in which practically all substances are affected by magnetic flux when sufficiently powerful.

The magnetic metals.

All substances affected by magnetic flux.

In 1778, Brugmans, of Leyden, while making some experiments on the action of magnetism on a lump of metallic bismuth, suitably suspended near the pole of a magnet, noticed that the bismuth was apparently repelled. In 1827, Becquerel observed that a similar action was produced in a lump of antimony under the same circumstances.

Brugmans and Becquerel.

Apparent repulsion of bismuth and antimony.

In 1786, Cavallo discovered that by the act of hammering, brass acquires magnetic properties. He also found that rhodium and iridium, when heated, were acted on by a magnet in the same manner as iron.

Cavallo.

Brass magnetized by hammering

In 1802, Coulomb made a number of experiments with slender needles of different substances, suspended between the poles of magnets, and endeavored to trace the influence the magnet poles exerted on such needle by causing them to swing while so suspended. He found that all the substances on which he experimented came to rest with their greatest length extended between the magnet poles. Coulomb believed that the cause of this similarity of action was to be traced to the presence of small quantities of iron existing as impurities in the different substances.

Coulomb's magnetic experiments.

In 1829, Arago extended these observations of Coulomb with the following modification; viz., instead of causing the substances to vibrate or oscillate when under the influence of a magnet pole, he kept the substances at rest, and endeavored to ascertain their influence on a magnetic needle brought near it, by causing the magnetic needle to oscillate or vibrate. He found that the influence of such substances, generally, was to check the oscillations of the needle, or to bring it to rest more quickly than if

Arago's experiments on vibrating needles.

it had not been in the neighborhood of the substance. He found that metallic substances, or good conductors of electricity, were especially able to thus check vibrations of the needle. We know now that such experiments were exceedingly deceptive, the effects being similar to those produced in the compass needle of Harris, to which we have already alluded. It can be shown that magnetic needles, when caused to move past metallic masses, set up electrical currents in such masses, and that it was these currents that affected the movements of the magnetic needle.

Source of error in Arago's experiments.

It was not until 1845, when the great Faraday investigated the matter, that a true light was thrown

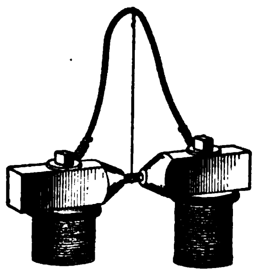


FIG. 109.—Action of Magnetic Flux on Bar of Paramagnetic Substance. Note the fact that the bar comes to rest with its longer axis in the same direction as that in which the magnetic flux passes from one magnet pole to the other. The heavy pole-pieces on the magnet serve to concentrate the magnetic flux.

on these curious phenomena. By employing very powerful magnetic flux, such, for example, as that produced by electro-magnets, Faraday found that all of the substances on which he experimented, whether solids, liquids or gases, were influenced by magnetism. Faraday shaped the substances on which he experimented in the form of slender needles or bars, and suspended them between the magnet poles, so as to be able to move readily in a

Faraday's researches on paramagnetic and diamagnetic substances.

horizontal plane like a compass needle. Under these circumstances he found that many substances acted like iron or steel, and came to rest, as shown in Fig. 109, with their greatest length in the direction in which the magnetic flux passed; *i.e.*, axially, or with their greatest length extending directly between the poles, as if they were attracted by magnetism. He found, however, that other substances, such as bismuth and antimony, acted as if they were visibly repelled by the magnetic flux. Such substances came to rest equatorially, as shown in Fig. 110, or with their greatest length at right angles to the direc-

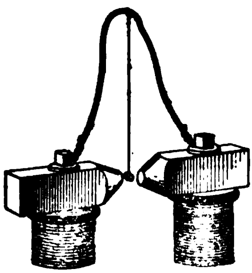


FIG. 110.—Action of Magnetic Flux on Bar of Diamagnetic Substance. Note that the bar comes to rest with its shortest dimensions in the direct path of the magnetic flux.

tion in which the magnetic flux was passing between the poles.

Faraday called substances that acted like iron paramagnetic; *i.e.*, magnetic after the manner of iron, and those that were apparently repelled, like bismuth and antimony, he called diamagnetic substances. When this distinction was recognized paramagnetic substances were sometimes called simply magnetic substances, or ferro-magnetic substances.

Para-magnetic or ferro-magnetic substances.

Faraday described the result of these experiments in a paper to the Royal Society of London, in 1845.

Before the time of these investigations it was believed that all substances are visibly magnetic, after the manner of iron, most, however, being influenced only to a very small degree. At first Faraday believed that he had demonstrated the existence, not of a weak magnetic force acting in the same direction as in iron, but of a new force acting in an absolutely opposite or reversed direction to what it does in iron. He believed that there existed a peculiar character of polarity in diamagnetic substances, which he called diamagnetic polarity, that is, a polarity the reverse of ordinary polarity. He believed that when a diamagnetic substance acted to produce magnetism by induction, it produced a pole of the same name, instead of, as in ordinary magnetism, a pole of an opposite name, and explained the repulsion which he thought took place, by the action of these similar poles.

Diamagnetic polarity.

Faraday's belief in a diamagnetic polarity is now generally discredited by scientific men. Indeed, Faraday himself, at a later date, abandoned this belief, although Weber and Tyndall refused to disbelieve in its existence. The explanation now generally given for the apparent repulsion of bismuth and other diamagnetic substances, when suspended in the shape of slender bars between powerful magnet poles, is as follows: The position the bar assumes is not due to any peculiar or diamagnetic polarity, but simply to the fact that the bismuth permits the lines of magnetic force to pass through it less readily than through the air which surrounds it. A movement, therefore, takes place in the substance suspended between the poles, until the air and the bismuth are arranged so as to offer the least resistance to the passage of the flux out of the north pole and into the south pole of the magnet. Now this will only be

General disbelief in the existence of a diamagnetic polarity.

Diamagnetic substances less permeable to magnetic flux than paramagnetic substances.

attained when the least dimensions of the bismuth and the greatest dimensions of the air are so interposed. Faraday showed that the oxygen of the air is paramagnetic, or magnetic after the manner of iron. It is, therefore, placed with its greatest mass directly between the poles, and this it can only do when the bismuth comes to rest with its least mass at right angles to such directions.

In the following list are given a number of para- and diamagnetic substances. **List of paramagnetic and diamagnetic substances.**

Paramagnetic	*Diamagnetic*
Iron	Bismuth
Nickel	Phosphorus
Cobalt	Antimony
Manganese	Zinc
Chromium	Tin
Cerium	Cadmium
Titanium	Mercury
Palladium	Lead
Osmium	Silver
Oxygen gas	Copper
	Gold
	Arsenic
	Water
	Alcohol
	Selenium
	Sulphur
	Hydrogen

Faraday found that all substances, whether solids, liquids, or gases, are acted on to some extent by magnetism. When experimenting with liquids, the liquids were sometimes placed in shallow glass vessels; for example, watch crystals, supported on the poles of powerful electro-magnets. Under these circumstances, paramagnetic liquids or solutions exhibited curious changes in shape while under the influence of the magnetic flux, being heaped up so as to place the greater part of their length in the direction of the flux, as shown at A, in Fig. 111, at the **Solids, liquids, and gases alike acted on by magnetism.**

top of the figure, while diamagnetic liquids assume such changes in shape as would place the greater part of their mass at right angles to this direction, as at B, at the bottom of the same figure. Sometimes, instead of placing the liquids in open glass vessels, they were placed in thin glass tubes. Such tubes, when filled with paramagnetic liquids, came to rest axially, like rods of iron, and, when filled with diamagnetic liquids, came to rest equatorially,

Experiments on liquid substances.

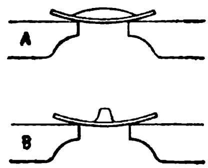


FIG. 111.—Action of Magnetic Flux on Paramagnetic and Diamagnetic Liquids.

like rods of bismuth. When glass tubes were employed, in order to avoid the influence exerted by the glass itself on the direction in which the tube would come to rest, the tube was made as thin as possible.

When experimenting on gases, the streams of the different gases, when permitted to flow between the magnet poles, were turned out of their course while under the influence of the magnetic flux. Since most gases are invisible, they were mixed with a sufficient quantity of smoke or some visible vapor. Candle and gas flames, consisting as they do of streams of heated gas, assume curious shapes when placed between powerful magnetic poles. The effect produced on the candle flame is shown in Fig. 112. This flame is diamagnetic. The effect of the magnetic flux, therefore, is to set the flame at right angles to the path of the flux.

Diamagnetic character of candle flame.

One of the most important results of these investigations of Faraday was the discovery of the paramagnetic character of oxygen, and of the neutral character of nitrogen. Since two-ninths of the weight of the atmosphere is composed of oxygen, a substance that is magnetic after the manner of iron, and since, moreover, this substance manifests marked changes in its magnetic properties with changes of temperature, it can be seen how strongly it would affect the direction of magnetic needles that are completely surrounded by it. Faraday pointed out that such changes in temperature would necessarily pro-

Faraday on the magnetic behavior of the principal constituents of the atmosphere.

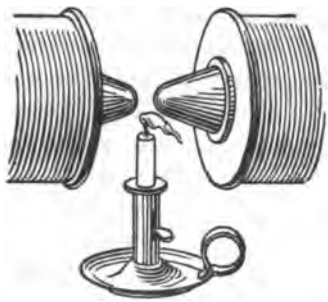


FIG. 112.—Diamagnetic Character of Ordinary Candle Flame. A species of blow-pipe operated by magnetic streamings.

duce changes in the direction of magnetic needles, and, as we have already seen, proposed a theory for the earth's magnetism based on this effect.

In his "Experimental Researches," No. 2847, Volume III., page 218, on "Atmospheric Magnetism," Faraday speaks as follows, as to the effect which the magnetic character of the oxygen of the air should have on the variations of the compass needle:

Quotation from Faraday's paper on "Atmospheric Magnetism."

"It is to me an impossible thing to perceive, that two-ninths of the atmosphere, by weight, is a highly magnetic body, subject to great changes in its mag-

netic character, by variations in its physical conditions of temperature and condensation or rarefaction (2780), and at the same time subject to these physical changes in a high degree, by annual and diurnal variations, in its relation to the sun, without being persuaded that it must have much to do with the disposition of the magnetic forces upon the surface of the earth (2796), and may perhaps account for a large part of the annual, diurnal and irregular variations, for short periods, which are found to occur in relation to that power. I cannot pretend to discuss this great question with much understanding, seeing that I have very little of that special knowledge which has been accumulated by the exertions of the great and distinguished laborers, Humboldt, Hansteen, Arago, Gauss, Sabine, and many others, who have wrought so zealously at terrestrial magnetism over the surface of the whole earth. But as it has fallen to my lot to introduce certain fundamental physical facts, and as I have naturally thought much upon the general principles which tend to establish their relation to the magnetic actions of the atmosphere, I may be allowed to state these principles as well as I can, that others may be placed in possession of the subject. If the principles are right, they will soon find their special application to magnetic phenomena as they occur at various parts of the globe."

The magnetic separation of oxygen from nitrogen in the atmosphere

It was while conducting the above investigations on para- and diamagnetism, that the thought suggested itself to Faraday that it might be possible to separate the oxygen and the nitrogen of the atmosphere by making use of the paramagnetic character of oxygen. Faraday apparently made a number of unsuccessful attempts to effect this separation. Notwithstanding his failure, he still believed that the

great difference between the magnetic character of oxygen and nitrogen should render their magnetic separation possible. Bearing in mind the exceedingly powerful magnetic fields that can be obtained to-day, it would seem that this idea of Faraday's might be carried out on a commercial scale by combining with powerful magnetism suitable differences of temperature.

The magne-crystallic force. During some of the many experiments tried by Faraday on the influence of magnetism on different substances, he noticed that certain crystalline bodies were differently affected by magnetism in different directions; for example, he found that a crystal of tourmaline, which generally acts as a paramagnetic substance, manifested diamagnetic properties if suspended in a certain direction. He also noticed the same thing in crystals of bismuth. From these results he concluded that there existed in crystals a peculiar variety of force, for which he proposed the name of magne-crystallic force. **Plücker's observation** Plücker, who studied these phenomena, asserted that a distinct relation exists between the shape of the ultimate particles or atoms of matter and their magnetic phenomena. This subject, however, is still to be regarded as somewhat obscure.

CHAPTER XXI

RELATIONS BETWEEN MAGNETISM AND LIGHT

"We have now a real undulatory theory of light, no longer based on analogy with sound, and its inception and early development are among the most tremendous of the many achievements of the latter half of the Nineteenth Century."—*Modern Views of Electricity*: LODGE

Influence of magnetism on light.

IN 1845, Faraday made some experiments in which he showed that, under certain circumstances, magnetism is able to affect light. As is well known, light is produced by very rapid to-and-fro motions, or vibrations, in an exceedingly rare, attenuated medium, called the luminiferous ether. This medium is practicallly without weight, and not only is believed to fill all space, but even to exist between the molecules and atoms of all matter. Indeed, in accordance with opinions generally held today, which discredit the atomic theory of matter, it is believed to exist even between the exceedingly small corpuscles of which the atoms of gross matter are now thought to be composed. Light is transmitted across space by means of vibrations; the light of the sun, for example, is transmitted across the space existing between the sun and the earth by means of vibrations or waves in the luminiferous ether.

The luminiferous ether.

Light vibrations extremely rapid.

The vibrations producing light are exceedingly rapid, varying according to the color of the light, from 477,000,000,000,000 vibrations per second in

red light, to 699,000,000,000,000 vibrations per second in violet light.

A ray of light is said to be polarized when its vibrations take place in one plane, polarized light differing from ordinary light, in, that in the latter, the plane in which the particles are vibrating is constantly changing its direction. Polarized light is readily obtained in a variety of ways; for example, Polarized light.

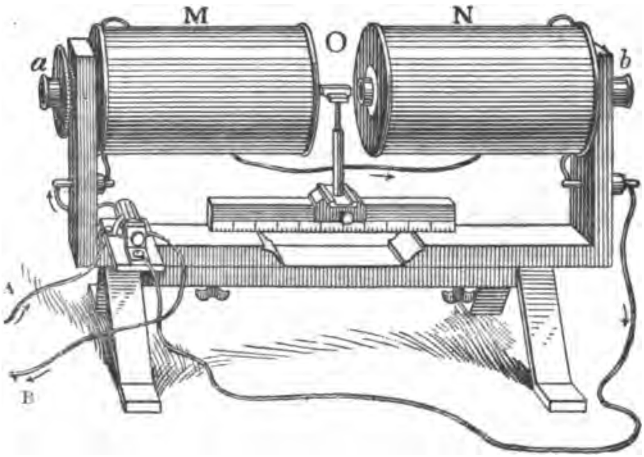


FIG. 113.—Apparatus for Experimental Demonstration of the Rotation of the Plane of Polarization of Light by the action of magnetic flux on a plate of a peculiar kind of glass.

by merely passing a beam of light through a thin slice of tourmaline, all the light that issues from the tourmaline plate has its vibrations limited to a single plane. In other words, the light is polarized.

Now, Faraday discovered that, when a ray of polarized light is passed through certain substances, in a direction parallel to that in which powerful magnetic flux is passing, the plane in which the light is polarized will suffer a rotation or turning while Magnetism rotating the plane of polarization of light.

the light is passing through the medium. In other words, that magnetism possesses the power of turning or rotating the plane or polarization of light.

Appara us for repeating Faraday's experiment.

The manner in which Faraday made this valuable discovery is shown in Fig. 113, where M and N, are two powerful electro-magnets employed to produce the necessary magnetic flux. The magnets employed here, as will be more thoroughly explained under the head of electro-magnetism, are practically of the horseshoe type, in which the magnetizing coils, M and N, are placed near the ends of the open rectangular frame, or flattened U-shaped mass of soft iron. The magnet cores, or the masses of iron inside the coils, M and N, are hollowed out, so as to permit a ray of light to readily pass through them. A small plate of a peculiar transparent glass is placed, on a suitably supported stand at O, directly in the path of the light, so that the light passes through both the glass plate and the hollow magnet cores.

The light.

The glass with which Faraday experimented, was a heavy glass made with a chemical substance called the boro-silicate of lead, and had been previously prepared by him during an entirely different investigation. The glass permits either ordinary or polarized light to pass through it without any change. When, however, an electric current is passed through the coils of wire wound on M and N, by connecting the terminals A and B, with a voltaic battery, or other source of electric current, as soon as the powerful magnetic flux passes between the poles of N and M, and through the heavy glass, it thereby acquires the property of turning or rotating the plane in which the light is polarized. The fact that this rotation occurs is rendered evident to the experimenter by certain optical devices employed at *a* and *b*, which it is not necessary to explain.

By Courtesy of the Brooklyn Edison Company

EXCAVATING WITH AN ELECTRICAL CONVEYOR

A contrivance which travels on an overhead wire between an excavation for a building and the waiting carts in the street, carrying out dirt and rubbish. It takes current from a trolley wire, and carries with it motor, switchboard, and operator

In the preceding apparatus, strictly speaking, the action of the magnetic flux is not exerted directly on the ray of light itself, but on the glass through which the magnetic flux is passing. There are other substances besides this particular heavy glass which possess, under ordinary conditions, the power of causing the plane in which the light vibrates to be slowly rotated, without being subjected to the influence of powerful magnetic flux. Such substances can be divided into two classes; viz., those which rotate the plane of polarization to the right, and those which rotate it to the left; or, as it is generally called, those possessing right-handed rotary polarization, and those possessing left-handed rotary polarization. Now the curious fact exists that all substances which acquire the power of rotating the plane of polarization only while under the influence of magnetic flux, as in the case of the heavy glass just referred to, can be caused to turn this plane either to the right or to the left, according to the direction in which the magnetic flux is passing through them. If, therefore, while the flux is passing from the right to the left, the plane of polarization be rotated in one direction, when the flux is caused to pass in the opposite direction, from the right to the left, the plane of polarization will be rotated in the opposite direction. There are many substances besides the heavy glass on which Faraday conducted his early experiment, which possess this power of rotating the plane of polarization only while under the influence of the magnetic flux. Such substances may exist in the solid, the liquid, and the gaseous condition or state.

Right and left-handed rotary polarization.

Direction of rotation of plane of light dependent on direction of magnetic flux.

The cause of the power thus acquired by transparent bodies of rotating the plane of polarization of a ray of light while it is passing through them, is generally ascribed to the strain produced in a trans-

parent material by the stress (*i.e.*, the pressure or pull producing the change of shape, deformation, or strain) caused by the magnetic flux. In 1877, Kerr discovered that the plane of polarization of a beam of light is turned or rotated by the mere reflection of the light from the polished pole of an electro-magnet, as shown in Fig. 114. Here M is the electro-magnet. The beam of light passes through A, a device for polarizing the light. C is a mass of soft iron employed for concentrating the magnetic flux in the space between the poles. B is another

Kerr on the rotation of polarized light by its reflection from a magnet pole.

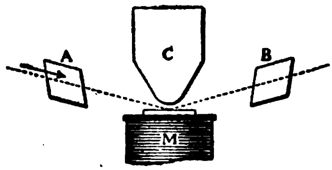


FIG. 114.—Rotation of Plane of Polarization by Reflection from Magnet Pole.

device for detecting the changes that have occurred in the light after its reflection from the magnet pole. Here the plane of polarization of the light is twisted or turned by the powerful magnetism which exists in the space between the magnet poles and the opposing mass of soft iron.

Effect of electro-static fields on polarized light.

Kerr has shown that a somewhat similar effect can be produced in transparent substances by subjecting them to the influence of electro-static fields; for example, by causing a beam of polarized light to be transmitted across the lines of an electro-static field.

Maxwell's electro-magnetic theory of light.

Clerk Maxwell, a distinguished mathematician, demonstrated mathematically, in 1864, that it should be possible to set up waves in the universal ether by means of electrical discharges, and proposed a theory

of light called the electro-magnetic theory of light. In this theory he showed that the phenomena of light, heat, electricity, and magnetism could be explained by assuming the existence of vibrations or oscillations taking place in the universal ether.

In 1882, Heinrich Hertz, by a brilliant series of experimental investigations, actually produced such waves by means of spark discharges from a Ruhmkorff coil passing through the air between polished metallic globes. In this way Hertz gave a physical demonstration of the existence of the waves which Maxwell had predicted some eighteen years previously. Electro-magnetic waves produced by Hertz in 1882.

Maxwell died before completing the details of his theory. He adduced sufficient evidence, however, before his death to show its probability, and Hertz's demonstration of the actual fact of electro-magnetic waves being produced, affords experimental proof of its correctness.

The waves or vibrations set up by disruptive spark discharges of the Ruhmkorff coil as employed by Hertz, are also produced by disruptive discharges of a Leyden-jar battery, or by the discharge of a condenser generally. Such discharges, as we have seen, consist of very rapid oscillatory movements to and fro, which very rapidly decrease in intensity, and die out. These oscillations set up in the ether waves or vibrations called electro-magnetic waves. As we shall shortly see in the study of the telegraph, it is waves of this character that are employed in the various systems of wireless telegraphy in carrying telegraphic communications across space without the use of any conducting wires. Electro-magnetic waves utilized in wireless telegraphy.

Some reasons for accepting Maxwell's electro-magnetic theory of light.

The theoretical considerations urged by Maxwell and others, together with some facts that were obtained since Maxwell's death, are, to a great extent, beyond the elementary character of this book. It will suffice, however, to state that there existed, many years ago, a very general belief among scientific men as to the extreme probability that the phenomena of light, electricity and magnetism are due to the same cause.

Correctness of the electro-magnetic theory of light undoubted.

To-day we know that light and electro-magnetic waves are one and the same phenomenon. We have succeeded in calculating the velocity with which electric radiations or waves move through free space, and we find that this velocity is the same as the velocity of light. We are, therefore, justified in believing that light and electric radiations are alike. The experimental evidence, however, does not stop even here. It is only through the ether of free space that the velocity of electric radiations and light is the same. In the fixed ether that exists between the ultimate particles of matter, the movements both of light and of electro-magnetic waves in different substances, are dependent on certain peculiarities of the ether in these substances. In the case of light we can compare the speed with which the light travels through free space, with the speed with which it travels through the ether that fills different substances, by reference to a physical quantity called the index of refraction; that is, a quantity which determines the amount the ray has been refracted or bent out of its course while passing from one medium to another, as from air to glass, or from air to water. Now it can be shown that the ability of any medium to permit induction to take place through its mass, together with its magnetic permeability, or the ease with which magnetic flux can

pass through it, should bear certain definite relations to the value of its index of refraction, and, although the evidence is not complete in this direction, yet it is sufficient to show that such relations actually exist. Thus again is demonstrated the extreme probability of the truth of the electro-magnetic theory of light.

Indeed, electricity is now so generally acknowledged as a phenomenon of light, and light a phenomenon of electricity, that we have a separate branch of electrical science called electro-optics. Or optics may be regarded as a branch of electricity. But this is only another way of stating the same fact.

Professor Oliver Lodge on the electro-magnetic theory of light.

Electro-optics.

As Maxwell himself has pointed out, if the electro-magnetic theory of light be correct, it should not be possible to transmit electro-magnetic waves through substances that are good conductors of electricity. Therefore, all conducting substances should be opaque to light. Now, in point of fact, most transparent substances are good electrical insulators, and most electrical conductors are opaque to light. Maxwell's discovery is very highly esteemed by scientific men. The following eloquent tribute by Prof. Oliver Lodge, is taken from his book entitled, "Modern Views of Electricity":

"On November 5 last year (1888) there died at Cambridge a man in the full vigor of his faculties—such faculties as do not appear many times in a century—whose chief work has been the establishment of this very fact, the discovery of the link connecting light and electricity; and the proof—for I believe it amounts to a proof—that they are different manifestations of one and the same class of phenomena: that light is, in fact, an electro-magnetic disturbance. The premature death of James Clerk Maxwell is a

loss to science which appears at present utterly irreparable, for he was engaged in researches that no other man can hope as yet adequately to grasp and follow out; but fortunately it did not occur till he had published his book on 'Electricity and Magnetism,' one of those immortal productions which exalt one's idea of the mind of man, and which has been mentioned by competent critics in the same breath as the 'Principia' itself.

"But it is not perfect like the 'Principia'; much of it is rough-hewn, and requires to be thoroughly worked out. It contains numerous misprints and errata, and part of the second volume is so difficult as to be almost unintelligible. Some, in fact, consists of notes written for private use, and not prepared for publication. It seems next to impossible now to mature a work silently for twenty or thirty years, as was done by Newton two and a half centuries ago. But a second edition was preparing, and much might have been improved in form if life had been spared to the illustrious author.

"The main proof of the electro-magnetic theory of light is this: The rate at which light travels has been measured many times, and is pretty well known. The rate at which an electro-magnetic wave disturbance would travel, if such could be generated, can be also determined by calculation from electrical measurements. The two velocities agree exactly. This is the great physical constant known as the ratio '*v*,' which so many physicists have been measuring, and are likely to be measuring for some time to come."

Morichini on the production of magnetism by violet light.

It will be interesting here briefly to allude to the production of magnetism directly from light, as claimed by Morichini, who, in 1813, made the assertion that on merely exposing a steel needle to violet

light obtained from the sun's rays, the needle was thereby magnetized. This experiment was subsequently repeated by Mrs. Mary Summerville, the author of a work on Natural Philosophy. Mrs. Summerville claims that after an exposure of a steel needle to violet light for a period of about two hours, the needle was permanently magnetized.

Playfair describes the following experiments conducted according to the instructions of Morichini:

Playfair on Morichini's experiment.

"The violet light was obtained in the usual manner, by means of a common prism, and was collected into a focus by a lens of sufficient size. The needle was made of soft wire, and was found, upon trial, to possess neither polarity, nor any power of attracting iron filings. It was fixed horizontally upon a support, by means of wax, and in such a direction, as to cut the magnetic meridian at right angles. The focus of violet rays was carried slowly along the needle, proceeding from the centre toward one of the extremities, care being taken never to go back in the same direction, and never to touch the other half of the needle. At the end of half an hour after the needle had been exposed to the action of the violet rays, it was carefully examined, and it had acquired neither polarity nor any force of attraction, but after continuing the operation twenty-five minutes longer, when it was taken off and placed on its pivot, it traversed with great alacrity, and settled in the direction of the magnetical meridian, with the end over which the rays had passed turned to the north. It also attracted and suspended a fringe of iron filings. The extremity of the needle that was exposed to the action of the violet rays, repelled the north pole of a compass needle. This effect was so distinctly marked, as to leave no doubt in the minds

of any who were present, that the needle had received its magnetism from the action of the violet rays."

Faraday in connection with Sir Humphry Davy, while at Rome, during 1814, repeated these experiments of Morichini in the latter's laboratory, but did not obtain satisfactory results. He thus refers to these experiments in Volume III., Page 19, of his "Experimental Researches in Electricity":

Faraday's rejection of Morichini's results.

"I say, for the first time, because I do not think that the experiments of Morichini on the production of magnetism by the rays at the violet end of the spectrum prove any such relation. When in Rome with Sir H. Davy, in the month of May, 1814, I spent several hours at the house of Morichini, working with his apparatus and under his directions, but could not succeed in magnetizing a needle. I have no confidence in the effect as a direct result of the action of the sun's rays; but think, that when it has occurred it has been secondary, incidental, and perhaps even accidental; a result that might well happen with a needle that was preserved during the whole experiment in a north and south position."

Christie asserts that violet rays will produce magnetism in steel.

At a later date, Christie read papers on the "Influence of Solar Rays on Magnets" before the Royal Society, in London, one in 1826, and the other in 1828, in which he claims that he obtained results similar to those of Morichini and Summerville. These experiments were repeated by Ries and Moser, who concluded that "they think themselves justly entitled to reject totally a discovery which, for seventeen years, has, at different times, disturbed science."

Although the conclusions of Ries and Moser, as given above, were generally coincided in by scientific

men, yet recently, facts have been discovered regarding certain peculiar effects produced by the ultra-violet; *i.e.*, the rays beyond the violet, or those produced by a greater number of vibrations per second than the violet, which have led at least some scientific men to conclude that, possibly, the violet rays of light may be able, under favorable conditions, to excite a permanent magnetism in steel bars.

Curious effects of the ultra-violet rays.

During his investigations on electrical radiations, Hertz noticed the peculiar effects that ultra-violet rays of light exert on the length of electric discharges. On one occasion, he was experimenting with two different sets of sparks, that were produced simultaneously. One of these was the discharged spark of the induction coil, that was employed to produce the primary oscillation, and the other spark was that of the induced secondary oscillation. Since the latter was very faint, and but feebly luminous, he placed the spark gap inside a dark chamber. As soon as this was done, he observed that the length of the spark was shortened, and that, at times, the spark even disappeared entirely. Investigating the cause of this phenomenon, he discovered that the ultra-violet rays emitted by the first spark markedly influenced the length of the induced spark, and this under conditions that could not possibly be referred to any screening effect of an electro-static or an electro-magnetic nature.

Hertz's discovery of the effect produced by the ultra-violet rays in increasing the sparking distance of disruptive electric discharges.

In other words, it was an effect produced, not by the visible portions of the spectrum, but by the invisible portions existing beyond the violet. In proof of this observation, Hertz found that the same effects were produced by a number of common sources of light, such as the flame of burning gas, wood, etc., as well as by non-luminous flames of alcohol and of

the ordinary Bunsen burner. The light from burning magnesium wire was found to be peculiarly effective; that of the ordinary limelight somewhat less effective; but, of all the sources of light, none produced effects equal to those caused by the spark discharge itself. In speaking of these results, Hertz says in his book on "Electric Waves":

Hertz on the effects of ultra-violet rays.

"According to the results of our experiments, ultra-violet light has the property of increasing the sparking distance of the discharge of an induction-coil, and of other discharges. The conditions under which it exerts its effect upon such discharges are certainly very complicated, and it is desirable that the action should be studied under simpler conditions, and especially without using an induction-coil. In endeavoring to make progress in this direction I have met with difficulties. Hence I confine myself at present to communicating the results obtained, without attempting any theory respecting the manner in which the observed phenomena are brought about.

"By this I did not mean to say that I had not succeeded in observing the action of light upon discharges other than those of induction-coils; but only that I had not succeeded in replacing spark-discharges—the nature of which is so little understood—by simpler means. This was first done by Herr Hallwachs. The simplest effect that I obtained was with the glow-discharge from 1,000 small Planté accumulators between brass knobs in free air; by the action of light I was able to make the glow-discharge pass when the knobs were so far apart that it could not spring across without the aid of the light."

In addition to the above, Hallwachs has shown that the mere exposure of a clean metallic plate to the action of light produces an electrification as soon

as the light strikes the plate. We are, moreover, acquainted with the facts concerning chemical effects of light, as seen in its action on the photographic plate, these effects being especially noticeable in those parts of the spectrum corresponding closely to the ultra-violet rays. It would seem that the rate of the ether vibrations, producing the ultra-violet rays, corresponds with the rate at which vibrations naturally occur in the molecules of sensitive silver salts. Unquestionably much is yet to be learned concerning the action of the ultra-violet rays of light on electric and magnetic phenomena.

Possibility of ultra-violet rays affecting magnetic phenomena

III

THE VOLTAIC CELL AND OTHER ELECTRIC CELLS

CHAPTER XXII

THE EARLY HISTORY OF THE VOLTAIC CELL

"Beware
Of entrance to a quarrel; but being in,
Bear't that the opposèd may beware of thee.
Give every man thy ear, but few thy voice;
Take each man's censure, but reserve thy judgment."
—*Hamlet*, Act I, Scene III.

DURING the two decades that preceded the beginning of the Nineteenth Century, a series of extremely important investigations was carried on by two scientific men in Italy. These investigations resulted in an invention which must be ranked among the most important that has ever been given to electric science. This was a new electric source; a source that produced electricity far more readily and in much greater quantities than had been possible by any previously existing device. These investigations were those of Galvani and Volta, and the invention was that of the voltaic pile or battery.

Galvani and Volta.

One might readily believe that so important an invention, occurring as it did not far from one hundred years ago, would have had so many historians to record its important facts, that no doubts whatever could possibly exist as to the minutiæ of even its least important details. Unfortunately, however, such is far from the fact, as we shall show when con-

Uncertainty of exact facts of Galvani's original discovery.

sidering these discoveries in such detail as we feel sure their importance will warrant.

In 1786, Luigi Galvani, Professor of Anatomy in the University of Bologna, while making a careful investigation of the effect of atmospheric electricity on animal organisms, had been employing the hind legs of some recently killed frogs, as delicate electroscopes. He had long known, at least it is so asserted, how exceedingly delicate a device such legs afforded for the detection of small electric charges. He was surprised, however, during these investigations, to note that when, as he believed, no electrical currents were passing through the legs of the frogs, they were convulsed just as he knew such electrical currents would affect them. Happening to place some frogs' legs, tied together in a bundle by a copper wire, against the iron railing in a window of his laboratory, he observed that, whenever a portion of the exposed vertebræ or backbone of the animal, which, together with some portions of the nerves, was still attached to the legs, touched the iron, the legs were powerfully convulsed.

The accidental convulsion of the frogs' legs.

At first Galvani thought that he had discovered the existence of a vital or nervous fluid in the animal, which, passing from the nerve to the muscle through the conducting path offered by the iron, caused the muscle to contract, just as an electric discharge would. Afterward, he correctly recognized the movements as due to electricity; but, curiously enough, did not trace the source of the electricity, as he should have done, to something outside the frog itself, but believed it to be due to electricity produced in the frog itself.

Galvani's failure to understand the real significance of his discovery.

If it be true, as appears to be the case, that Galvani was aware of the fact that the legs of the frog

were affected by exceedingly feeble electric currents, it seems curious that he should have lost sight of the possibility that such movements of the legs were due to currents obtained in some way from sources outside of the animal. It is also curious, that if he was well acquainted with the principles of electricity, as also appears to be the case, he should not have understood the possibility of the convulsive movements being due to electrical charges passing through the animals, derived by induction from the discharges of an electrical machine, which was in operation in his laboratory. This, however, was probably another instance of what so often takes place in our everyday life. We are prone to find only what we hope to find, and, indeed, often deceive ourselves in believing that we have at last found that which we earnestly hoped to discover.

Why Galvani failed to correctly interpret his experiment.

Galvani hailed the convulsive movement of the frogs' legs as a proof that he had at last unearthed that elusive fluid, or "vital force," for which he, in common with other anatomists and scientific men generally, had been so long searching. Although, as we have seen, he afterward somewhat modified this theory of a vital fluid, and attributed the result to electricity, yet he still maintained that the electricity was produced not outside the animal, but within the animal itself. He believed that a decomposition occurred of the animal electricity at the junction between the nerves and the muscles, the positive charge going to the nerves and the negative charge to the muscles, and, moreover, that this combination presented an analogy between the opposite coatings of a Leyden jar.

Galvani's interpretation of his experiment.

According to another account, however, Galvani is given less credit for his discovery, it being alleged

that it was entirely due to the accidental circumstance that Madame Galvani, his wife, had been suffering from a cold, and that her physician had ordered for her diet a broth made of frogs. Some frogs' legs, prepared for this broth, so the story runs, were lying on a table in Galvani's laboratory, and it chanced that one of his assistants accidentally touched one of the legs with his scalpel during the time that electrical discharges were being produced by an electrical machine in his laboratory. Instantly the legs were convulsed. Madame Galvani, who was present, noticed that these discharges occurred simultaneously with the discharges from the electrical machine. Galvani, on being notified of this fact by his wife, made extensive researches in this matter. This is alleged to have occurred at another date; viz., in 1790.

The story of Madame Galvani and the broth of frogs' legs.

Many able physicists at the time credited this story of the frog broth. "It may be proved," says Arago, "that the immortal discovery of the voltaic pile arose in the most immediate and direct manner from a slight cold, with which a Bolognese lady was attacked, in 1790, for which her physician prescribed the use of frog broth."

Arago and the story of the broth of frogs.

Dr. Lardner, in one of his scientific works, thus repeats this story:

"Galvani was not familiar with electricity; luckily for the progress of science, he was more an anatomist than an electrician, and beheld with sentiments of unmixed wonder the manifestation of what he believed to be a new principle in the animal economy; and, fired with the notion of bringing to light the proximate cause of vitality, engaged with ardent enthusiasm in a course of experiments on the effects of electricity on the animal system. It is rarely that

an example is found of the progress of science being favored by the ignorance of its professors.

Lardner on the story of the frog broth.

"Chance now again came upon the stage. In the course of his researches he had occasion to separate the legs, thighs, and lower parts of the body of the frog from the remainder, so as to lay bare the lumbar nerves. Having the members of several frogs thus dissected, he passed copper hooks through part of the dorsal column which remained above the junction of the thighs, for the convenience of hanging them up till they might be required for the purpose of experiment. In this manner he happened to suspend several upon the iron balcony in front of his laboratory, when, to his inexpressible astonishment, the limbs were thrown into strong convulsions. No electrical machine was now present to exert any influence."

Proof of Galvani's knowledge of action of electricity on frogs' legs.

It would appear, however, from a careful study of all the evidence, that, despite the assertion of Lardner to the contrary, Galvani was well acquainted with the facts of electricity, and had, as we have already stated, employed the legs of frogs as delicate electroscopes. Indeed, there has recently been found among his old manuscripts, since published by the Academy of Science of Bologna, one dated as early as 1780, in which, referring to these experiments, Galvani states that the frog was prepared as usual. From this it would certainly appear that this was not his first experiment with frogs.

In Fig. 115, are shown frogs' legs prepared according to Galvani's method. Here the head and the upper part of the animal have been cut away and the animal skinned, so as to expose the nerves and muscles of the leg. If now, a copper and a silver wire be joined in contact at one end, as shown in the figure,

and one of these wires be placed on the exposed nerve near the vertebræ, and the other on a part of the muscle of the leg, convulsions at once occur.

The following description of the method generally adopted at that time for the preparation of frogs for this purpose is thus given in the American edition of Cavallo's "Natural Philosophy," published in America, in 1824:

Cavallo's directions for preparing the frog's legs.

"Separate with a pair of scissors the head and upper extremities of a frog from the rest of the body. Open the integuments and muscles of the abdomen, and remove the entrails, by which means you will lay bare the crural nerves. Then pass one blade of

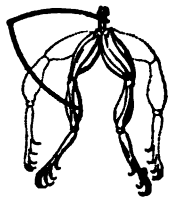


FIG. 115.—The Galvanoscopic Frog Preparation.

the scissors under the nerves, and cut off the spine with the flesh close to the thighs, by which means the legs will remain attached to the spine by the nerves alone. This done, leave a small bit only of the spine attached to the crural nerves, and cut off all the rest. Thus you will have the lower limbs of the frog adhering to the bit of spine by means of the crural nerves. The legs must be flayed in order to lay bare the muscles; and a bit of tin-foil should be wrapped round the spine. With this preparation the experiment may be performed in various ways, but the two which follow are the best.

"Hold the preparation by the extremity of one leg, the other leg hanging down, with the armed

bundle of nerves and spine lying upon it. In this situation interpose a piece of silver, as a half-crown, between the lower thigh and the nerves, so that it may touch the former with one surface, and the metallic coating of the latter with the other surface, or with its edge; and you will find that the hanging leg will vibrate very powerfully, sometimes so far as to strike against the hand of the operator, which holds the other leg."

Galvani extended his experiments to other animals besides frogs. All the animals tried manifested

Fig. 116.—Aldini's experiment with a frog's-leg galvanoscope, operated by means of an electric current obtained from the head of a recently killed ox.

Cold-blooded animals affected for much longer time after death than warm-blooded animals.

convulsive twitchings on the application of electricity. He found, however, that cold-blooded animals, like frogs and fish, were affected in this way a much longer time after death than warm-blooded animals. But what is most interesting in these electrical experiments of Galvani, was the fact that he actually demonstrated the existence of electric currents in the bodies of animals themselves; for he obtained convulsive movements of the frog's legs by mere contact with different parts of the animal itself. The

existence of such electrical currents in animals other than the frog was demonstrated, at a later date, by Aldini, a nephew of Galvani, as follows. Taking the head of a recently killed ox, he succeeded in obtaining sufficiently powerful currents from it to convulse the legs of a recently killed frog. The frog's legs were grasped in one hand, which was moistened with salt water in order to improve the electrical contact between the hand and the frog, in the manner shown in Fig. 116. He then placed the legs on the tongue of the ox, while at the same time he grasped an ear of the animal in the other hand, similarly moistened with salt water. The convulsions of the frog's legs, that immediately occurred, showed that sufficient current was supplied from the head of the ox to produce such movements.

Aldini's experiment with head of recently killed ox.

The sensibility of the ordinary snail to electrical currents can be shown by the following simple experiment. Place a small copper coin on a zinc plate much larger than the coin itself. Put a common garden snail on the zinc plate, so that it will crawl toward the copper coin. Note that, whenever the snail attempts to cross from the zinc to the copper, it will shrink back as if shocked, and that, probably, after a few trials, it will henceforth avoid the copper. Here electrical currents are produced by the action of the fluids in the body of the snail on the zinc.

Experiment with a common snail.

In all experiments on convulsive movements produced in animals after death, the amount of the convulsions is greater immediately after the animal has ceased to live. In most animals, however, sensibility continues for some time after death.

Long before Galvani's experiment on the frog's legs, Swammerdam, in 1678, exhibited an almost

Galvani antedated by Swammerdam in 1678.

identical experiment to the Grand Duke of Tuscany. Swammerdam took a portion of a recently killed frog, to which the nerve and muscle were still attached, and noted the production of marked convulsions in the muscles whenever a silver wire was brought in contact with a copper wire connected to the muscle. This experiment was made long before the time of Galvani, but we believe that Galvani himself was honestly ignorant of its existence.

Sulzer on peculiar taste, in 1767.

More than three-fourths of a century after this experiment of Swammerdam, Sulzer, in 1767, called attention to the fact that a piece of silver and a piece of lead, connected together and then placed on the tongue, caused a peculiar taste to be perceived, not unlike that produced by copperas or green vitriol. This taste closely resembles that caused by the current from any electrical source, such as a voltaic battery, when passed through the tongue; but this last fact is not mentioned by Sulzer.

Park Benjamin on the first suggestion of the voltaic pile.

Park Benjamin, in his excellent book on the "Voltaic Cell," refers to this observation of Sulzer, as the first suggestion of the voltaic cell. We regret that we can not agree with him in this conclusion, since there is nothing whatever in the original Sulzer article which shows that Sulzer was aware of the fact that the phenomena he was describing were electric. All he said was as follows:

"It must, therefore, be concluded that the junction of the two metals, acting either on one or on both, produces a vibration of their particles, and that these vibrations necessarily affect the nerves of the tongue and produce the sensation of taste."

That a voltaic couple was produced by Sulzer in this experiment there can be no doubt; but there is

no evidence to show that he recognized the fact that he had produced electricity. It would be fairer and truer to accord to Swammerdam the honor of having made the first suggestion of the voltaic cell, since he, so far before the time of Sulzer; viz., 1678, exhibited experimental results almost identical with those of Galvani. We believe, however, that it is to Galvani, and neither to Swammerdam nor Sulzer, that the credit for this discovery should be given, since Galvani was the first to so bring the observation before the scientific world as to attract attention to its importance, and this led Volta, at a later date, to make the real discovery of the voltaic cell.

Galvani, and neither Swammerdam nor Sulzer, entitled to credit for crucial observation.

Quite naturally the announcement by Galvani of his discovery of the existence of a vital fluid or species of animal electricity created an intense enthusiasm in the scientific world, especially among his countrymen. Hosts of experimenters in all parts of the civilized world repeated and modified Galvani's experiments, and made extended researches in this new field. Prominent among these was Alexander Volta, Professor of Natural Philosophy in the University of Pavia, Italy. At the first Volta adopted Galvani's views that the phenomena of the frogs' legs were due to the action of a vital fluid. Careful experimentation, however, soon convinced Volta that what Galvani had discovered was neither a vital fluid nor animal electricity, but an entirely new source of electricity; that the convulsions of the frogs' legs were due to electricity produced by the mere contact of dissimilar metals.

The convulsions of the frogs' legs convulse the whole scientific world.

Volta repeats Galvani's experiments.

Volta endeavored to prove the correctness of his contact theory by many experiments. Since the electro-motive forces produced by contact were exceedingly small, he devised a special form of elec-

Volta and his contact theory

Volta's condensing electroscope.

troscope for the purpose of measuring them. This instrument, called by Volta his condensing electroscope, is shown in Fig. 117. It consists of an ordinary gold-leaf electroscope, on the top of which is placed a metallic plate in electric contact with the gold leaves. This plate is covered with a waxed silk cloth, somewhat larger than the plate itself, and on this is placed a second metallic plate of the same size as the first, and provided with an insulating handle of glass.

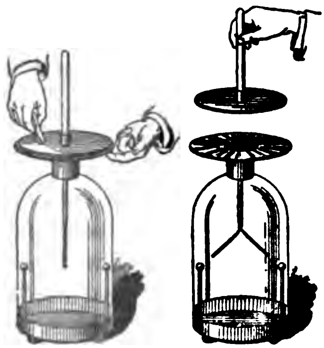


FIG. 117.—Volta's condensing electroscope, employed by him in his experiments in the production of electricity by the contact of dissimilar substances.

Method of using the condensing electroscope.

The condensing electroscope is used as follows: The top of the upper plate is touched by the body whose visible charge is to be measured, while a finger of the hand touches the lower plate, as shown on the left-hand side of the figure. Under these circumstances, a gradual accumulation of the electric charge occurs in the manner we have already explained in connection with the action of the Leyden jar. No divergence of the gold leaves takes place until the upper plate is lifted, when, as shown at the right-hand side of the figure, the leaves are at once repelled. Two little balls of polished brass, placed at the sides of the instrument near the lower ends of

the gold leaves, increase the divergence of the gold leaves by means of inductive action.

Volta ascribed the production of electricity in the case of the frogs' legs entirely to the contact of dissimilar metals, losing sight of the fact that chemical action invariably takes place, due either to the moisture of the hands or to the oxygen of the air. He noted, in the case where the two metals were copper and zinc, that the zinc received a positive or plus charge, and the copper a negative or minus charge, and that the E.M.F.'s, causing such charges, were produced by contact.

E.M.F.'s produced by contact.

At the outset of these experiments, Volta ascertained for himself the extreme sensibility of the frogs' legs to electric discharges, and noted the fact that electric discharges, capable of causing convulsions, were too feeble to affect his sensitive condensing electroscope. Cavallo, who also made experiments on this subject, states that a frog galvanoscope, as the preparation of frogs' legs is sometimes called, will respond to, approximately, the one-hundredth part of the electricity required to affect a delicate electrometer, by which, of course, we must understand the delicate electrometer as it existed at that time.

Cavallo on the sensitiveness of frogs' legs electroscopes.

Volta's experimental researches soon led him to the important discovery that the best results were obtained when couples or pairs of different metals were placed in contact with each other. The results obtained were especially marked when one of these metals was oxidizable, and when they were employed in combination with certain acid or saline solutions. Such combinations, he found, were capable of disengaging electricity, and charging condensers.

Conditions under which contact produces the best results.

Volta's contact series.

Volta arranged the two unlike metals or other substances, the contact of which he claimed produced the electricity, in a series called the contact series. In this series the order of the metals is such that each metal becomes positively electrified or charged when placed in contact with any metal below it in the series.

Contact series.

Contact series of metal in air (S. P. Thompson):

+*Sodium.*
Magnesium.
Zinc.
Lead.
Tin.
Iron.
Copper.
Silver.
Gold
Platinum.
—*Graphite* (Carbon).

E.M.F.'s produced by contact series.

The actual values of the E.M.F.'s produced by such contact, as determined by measurements by Professors Ayrton and Perry, are given in the following table:

	Difference of potential in volts
Zinc / Lead	.210
Lead / Tin	.069
Tin / Iron	.313
Iron / Copper	.146
Copper / Platinum	.238
Platinum / Cork	.113

The discovery by Volta of the contact series soon led him to a second and greater discovery; viz., that

By courtesy of the "Scientific American"

ELECTRIC CANAL HAULAGE

The mule may be superseded on the tow-path by the motor. In this country and in Germany considerable experimenting has been done. The single-track system of Koettgen, here illustrated, has been used on the Finow Canal

of the voltaic cell or battery. This discovery or invention was made by Volta in 1796. Volta disclosed his discovery in a letter to Sir Joseph Banks, who read it to the Royal Society on June 26, 1800. This letter is as follows:

Volta's grand discovery of the voltaic pile.

"After a long silence, for which I do not attempt to excuse myself, I have the pleasure, Sir, to communicate to you, and through you to the Royal Society, some striking results which I have just obtained, in carrying on my experiments on the electricity excited by the simple, mutual contact of different kinds of metals, and even by that of other conductors, sufficiently different from one another, either liquids or substances containing some moisture, to which strictly speaking they owe their conducting powers. The principal of these results, which includes nearly all the others, is the construction of an apparatus which resembles so far as its effects are concerned, that is by the commotion which it is capable of making one feel in the arms, etc., the Leyden batteries, and still more the fully-charged electric batteries. It acts, however, without ceasing, and its charge re-estáblishes itself after each explosion. It operates, in a word, by an indestructible charge, by a perpetual action or impulse on the electric fluid.

Volta's letter to Sir Joseph Banks announcing his discovery of the pile.

"I will here give you a detailed description of this apparatus.

"I obtain several dozen small round plates or disks of copper, brass, or better of silver, an inch in diameter, more or less; for example coins, and an equal number of plates of tin, or, what is still betber,of zinc,of the same shape and size approximately; I say approximately, because precision is not requisite; in general, the size as well as the figure of the metal pieces is arbitrary; we should have care only that we can conveniently arrange them one over the

other in the form of a column. I prepare besides a sufficiently great number of disks of cardboard, or cloth, or of some other spongy material, capable of imbibing and retaining considerable water or other liquid; for, it is necessary for the success of the experiment that they should be well moistened.

Volta's description of his pile.

"These sections or disks, which I will call moistened disks, are made slightly smaller than the metal disks, in order that they may be interposed between the other disks without projecting beyond them.

"Having these pieces conveniently arranged, and in good condition, that is to say the metal disks clean and dry and the non-metallic disks sufficiently

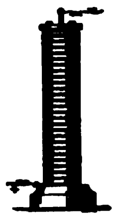


FIG. 118.—Volta's Pile or Battery, sometimes called Volta's Column.

moistened with water, or what is still better, salt water; they are then lightly pressed in order to prevent the liquid from running out. I have then only to arrange them as desired, and this arrangement is simple and easy.

"I place, generally horizontally, on a table or other base, one of the metallic plates, for example, one of silver; on this first, I then place a second of zinc; on this second, I place a moistened disk; then another plate of silver, followed immediately by another of zinc, to which I can make succeed a moistened disk. I then continue in the same manner coupling a plate of silver with one of zinc, and always in the same direction; that is to say, always the silver above, the zinc below, or vice versa, according as I

have commenced, interposing between each two of these disks a moistened disk; I continue, I say, to form by many of these sets a column sufficiently high that it may be able to stand upright."

The general appearance of Volta's original pile is shown in Fig. 118. It consisted of alternate disks of copper and zinc, separated from each other by a disk of cloth moistened with water containing some saline substance. These were placed in a pile, care being taken to preserve the same order of arrangement throughout; viz., copper, cloth, zinc; copper, cloth, zinc; etc., one end of the pile ending in a plate of copper, and the other in a plate of zinc. This instrument was called the voltaic pile, from the fact that the plates were thus piled on one another. It was called a battery from the similarity of the arrangement, from an electrical point of view, to the Leyden-jar battery. Indeed, the voltaic battery may be regarded as a variety of electrical battery, which, unlike the Leyden-jar battery, possesses the power of continually recharging itself on being discharged, and thus producing a continual discharge, flow, or current of electricity so long as certain necessary conditions are preserved. The separate or alternating plates or disks are firmly pressed together and placed inside a suitable frame, shown in the figure.

Comparison of a voltaic pile to a Leyden-jar battery.

The invention of the voltaic pile may justly be regarded as of great importance to electrical science. For the first time there was placed in the hands of scientific men a ready means for obtaining a continual flow of electricity. Although the electromotive forces produced by the voltaic battery were exceedingly small, when compared with the electromotive forces produced by the frictional and influence machines, that were practically the only sources

Great value of the invention of the voltaic pile.

of electricity before the invention of the voltaic cell, yet the quantity of electricity so set in motion was much greater than in the case of frictional or electrostatic induction machines. It is not surprising, therefore, as we shall see when we come to discuss some of the other branches of electric science, that it was at the time of the invention of the voltaic pile, and by its means, that investigations were extended in other fields of electric research, which were of the greatest importance to the electric arts and sciences of to-day.

Scientific discoveries immediately follow the invention of the voltaic battery.

As we have seen, Volta ascribed the cause of the electricity produced by his pile, to the mere contact of dissimilar substances. During Volta's time this explanation was adopted by many eminent scientific men, but doubts soon began to arise in the minds of some as to the correctness of this view, and another theory was proposed as to the cause of the electricity. This new theory attributed the cause to chemical action, and not to contact. There thus arose that celebrated scientific controversy between the advocates of the contact theory of the voltaic pile on the one side, and the advocates of the chemical theory of the voltaic pile on the other, which was eagerly entered into by nearly every scientific man in the world. Once in this controversy, or quarrel, it behooved them to take Shakespearean advice as found in the quotation at the beginning of this chapter. It was during this controversy as to the origin of the electricity in the voltaic cell, as has wittily been said, that enough ink was spilled in the preparation of the learned treatises by one side or the other to float all the royal navy of England. The controversy was not only waged during Volta's time, but continued long after his death, and, indeed, in some respects, still continues. We say some respects,

Celebrated scientific controversy between the contact and the chemical theories for the action of the voltaic battery.

because, as we shall show, with some reservations, the chemical theory is now generally accepted.

In a paper, read by Faraday, before the Royal Society, on February 6, 1840, the matter is thus referred to by the author, who publicly takes his position as an advocate of the chemical theory:

"What is the source of power in a voltaic pile? This question is at present of the utmost importance in the theory and to the development of electrical science. The opinions held respecting it are various; but by far the most important are the two which respectively find the source of power in contact, and in chemical force. The question between them touches the first principles of electrical action; for the opinions are in such contrast, that two men respectively adopting them are thenceforward constrained to differ, in every point, respecting the probable and intimate nature of the agent or force on which all the phenomena of the voltaic pile depend.

Faraday on the source of electricity in the voltaic pile.

"The theory of contact is the theory of Volta, the great discoverer of the voltaic pile itself, and it has been sustained since his day by a host of philosophers, among whom, in recent times, rank such men as Pfaff, Marianini, Fechner, Zamboni, Matteucci, Karsten, Bouchardat, and as to the excitement of the power, even Davy; all bright stars in the exalted regions of science. The theory of chemical action was first advanced by Fabroni, Wollaston, and Parrot, and has been more or less developed since by Oersted, Becquerel, De la Rive, Ritchie, Pouillet, Schoenbein, and many others, among whom Becquerel ought to be distinguished as having contributed, from the first, a continually increasing mass of the strongest experimental evidence in proof that chemical action always evolves electricity; and De la Rive should be named as most clear and con-

stant in his views, and most zealous in his production of facts and arguments, from the year 1827 to the present time.

"Examining this question by the results of definite electro-chemical action, I felt constrained to take part with those who believed the origin of voltaic power to consist in chemical action alone."

Galvanism *vs.* voltaism.

The electrical phenomena produced by the voltaic pile or battery, are sometimes referred to under the name of galvanic electricity, the subject itself being called galvanism. By others these are called respectively voltaic electricity and voltaism. The latter terms would appear to be more in accordance with facts, since it was Volta, and not Galvani, who discovered the means by which such phenomena are produced. Indeed, at the present time, the words galvanic electricity and galvanism are seldom employed, except by some electro-therapeutists.

Fabroni dissents from contact theory.

Fabroni, referred to in the above quotation from Faraday, in a communication to the Scientific Academy of Florence, in 1799, was the first prominent scientific man who publicly asserted his belief in the chemical origin of voltaic electricity. He observed, among other phenomena, the fact that mercury retains its metallic lustre for a long time, if kept from contact with other metals, but that, when in contact with such metals as zinc, it becomes rapidly oxidized. He noticed similar effects with a variety of different metals, and from these observations concluded that voltaic electricity must be ascribed to chemical action, and not to contact.

It will be impossible, from want of space, to do anything more than to briefly mention some of the many objections that have been urged against the

contact theory of voltaic electricity. Faraday, who made extended researches in this direction, became, as a result of this work, a strong adherent of the chemical theory. He very significantly calls attention to the fact that the contact theory necessitates a belief in the production of a force capable of overcoming resistance and doing work, such, for example, as that required for the decomposition of chemical substances, without attempting to point out the origin of such force, a belief to which he is necessarily unable to subscribe, since such would be the creation of power.

Faraday's objection to the contact theory.

Sir William Snow Harris also expresses himself in favor of the chemical theory, and asserts that the facts in the case are overwhelmingly in its favor. He calls attention to the significant fact that any increase or decrease in the amount of chemical action in a voltaic cell is followed by a corresponding increase or decrease in the amount of the electricity it produces, and that when the chemical action in such cell ceases, so also does its production of electricity.

A very significant fact, to which attention was frequently called during this celebrated controversy, was that the order of arrangement of the contact series is practically the same as that which marks the ability of the metals to be oxidized by air.

Order of contact series an argument for the chemical theory.

It will be well to enter now into an explanation as to the parts that it was urged are played both by the contact of the dissimilar metals, and by the chemical action in the voltaic cell.

Let us suppose that a bar of zinc and a bar of copper of equal length be bent so as to form a rectangle when placed together, and when so placed the junc-

No electric current in closed metallic circuit formed of unlike metals.

tions are soldered or welded together, as shown in Fig. 119. Under these circumstances, there will be formed a complete conducting path, but so long as there is no difference of temperature between the junctions, *i.e.* so long as all parts of the rectangle

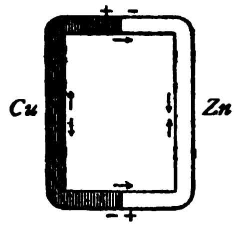


FIG. 119.—Closed Metallic Circuit showing that whatever contact E.M.F.'s may exist neutralize each other or cancel out.

Current only set up when chemical action is maintained in closed circuit.

are at the same temperature, no electrical currents will be produced. If there be any contact E.M.F.'s here, they are necessarily oppositely directed, and therefore cancel or wipe each other out. Now let us suppose that an opening be made in the ring at one of the junctions, so that the rectangle assumes

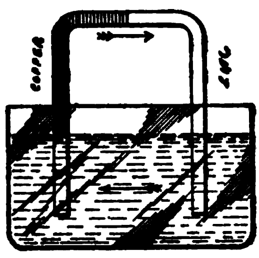


FIG. 119A—Modification of Rectangle of Fig. 119 so as to produce electric current.

the shape shown in Fig. 119A, and that the free ends of the rectangle be dipped in a dilute solution of sulphuric acid and water, or in any other liquid that is capable of acting chemically on the zinc. Immediately there will be differences of potential set up and

an electrical current will begin to flow, and will continue to flow as long as there is any zinc to be acted on, or any sulphuric acid or other liquid to dissolve the zinc.

It will be observed that the path of the current, *i.e.* the electric circuit, is formed in part by the liquid between the metals, as well as by the substances of the metals themselves. The direction in which this current flows is indicated by the arrows. Here we have the combination of two dissimilar metals with a substance capable of dissolving one of the metals and entering into combination with it. It, therefore, corresponds to the combination employed in Volta's original pile, the bar of zinc and the bar of copper corresponding to the disks of zinc and copper, and the liquid to the moistened disk of cloth placed between them.

Direction of electric current through closed voltaic cell.

Now we know that in order to maintain a continuous electric current a difference of electric potential or a difference of electric pressure must be maintained, and to maintain such difference of potential requires the expenditure of energy. This energy is evidently liberated during the combination of the zinc with a part of the liquid in which it has been placed. In other words, the current is maintained practically by the burning of the zinc by the liquid in which it is dipped. Chemical energy is, therefore, the cause which maintains the electric current in the voltaic battery.

Expenditure of energy required to maintain current in voltaic cell.

If the zinc be amalgamated; *i.e.*, covered with a thin film of mercury, by first dipping the zinc in dilute sulphuric acid and then rubbing its surface with mercury, and the rectangle be so arranged that an opening can be made at the top as well as at the

Simple voltaic cell on open and on closed circuit.

bottom; we will then have the arrangement shown in Fig. 120, at the left-hand side, where a separate plate of zinc and a separate plate of copper are dipped in a liquid. Under these circumstances, if the wires, or conductors connected with the tops of the plates, be kept separated, no chemical action will take place; but if such a connection be made, as shown at the right-hand side of the figure, a current of electricity will immediately flow through the combination from the zinc to the copper through the liquid, and from the copper to the zinc outside the

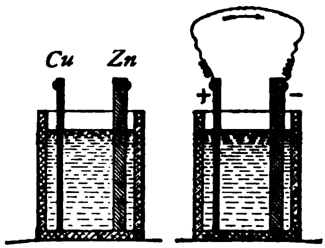


FIG. 120.—Simple Voltaic Cell on closed circuit. Note the direction of the current.

liquid, and this flow will continue as long as any zinc remains to be dissolved in the liquid, or any liquid remains to dissolve it.

Significant differences in phenomena of open-circuited and closed-circuited voltaic cell.

The following differences exist between a voltaic cell when on open and when on closed circuit. If the zinc be not amalgamated, then on open circuit, as at the left-hand side of the figure, the following actions will take place: The sulphuric acid acts on the zinc, hydrogen gas is liberated at the surface of the zinc plate, but no change occurs in the copper plate. All the energy liberated during the action of the sulphuric acid on the zinc appears in the form of heat, which raises the temperature of the liquid.

When, however, the circuit of the voltaic cell is closed, as shown at the right-hand side of the figure, the zinc is still attacked, though not at the same rate as before. But there are now two differences that should be carefully noted; viz., the hydrogen is liberated practically only at the surface of the copper plate, and the energy liberated by the chemical action of the sulphuric acid on the zinc no longer appears as heat in the cell, but as electric energy in the circuit of the cell. The origin of the electric energy of the voltaic cell is therefore the chemical energy liberated during the burning or combination of the zinc with a part of the sulphuric acid. In this sense, therefore, the production of electric energy is a case in which heat of a chemical origin has been transformed into electric energy.

Chemical theory of voltaic cell correct.

It should always be carefully borne in mind, in considering the chemical and contact theories of the voltaic cell, that, although voltaic contact E.M.F.'s are produced, they practically only exist when the voltaic cell is on open circuit. As soon as the circuit of a voltaic cell is closed, the sum of all the separate contact E.M.F.'s cancels out. In other words, the opposite contact E.M.F.'s produced neutralize one another. Such E.M.F.'s therefore cannot be the source of the current of the cell.

Contact E.M.F.'s only present in open-circuited voltaic cell.

We are, therefore, justified in saying that to-day practically all scientific men are advocates of the chemical theory of the voltaic cell, and that the contact theory has been rejected as being at variance with the doctrine of the conservation of energy. Unfortunately, however, this controversy has taken another direction on which scientific opinion is still divided, and this is as to what point in the voltaic circuit we may regard as the seat of the E.M.F.'s

Controversy as to seat of the E.M.F.'s of a voltaic cell.

produced. It will not be advisable in an elementary book to discuss this question as to the true seat of the E.M.F.'s of the voltaic cell. The following quotation, taken from one of the latest works on this subject; viz., on "Primary Batteries," by W. R. Cooper, will explain how the matter is regarded at the present day:

Cooper on the seat of the E.M.F.'s of the voltaic cell.

"Perhaps the safest conclusion to which a consideration of the various theories leads is that the whole matter is largely a question of definition, and that it is, therefore, of relatively very small importance. It depends a great deal upon the point of view, and so we can not say that one theory is correct and another necessarily wrong. This statement is also true of many other phenomena, as pointed out by Willard Gibbs. For example, some people might say that the circulation of water in a hot-water system is due to the action of gravity upon the vertical columns of water at different temperatures and having different densities; others might say that it is due to the furnace.

"Our ideas are naturally based upon processes most familiar to us. Being accustomed to the flow of water under the action of gravity, we are struck with a similarity of electric flow, and thus we are tempted to carry the analogy too far. It is convenient to think of electricity being raised in potential at some point in the cell, just as a pump raises water to a higher level, keeping up a continuous stream and enabling the water to do work by its downward flow. But the pump is not necessarily placed where the water gains potential energy. We may, of course, define the seat of E.M.F. as the point where energy is given to the circuit, but that is only a definition, and we can not always decide upon the position of such a point."

CHAPTER XXIII

THE VOLTAIC CELL

"The most important problem now before the electrical investigator is the production of cheap electricity. The principal modes by which this may be attained are, first, improvements in steam boilers and engines, gas-engines, and other existing transformers of power; second, the utilization of the natural powers, such as waterfalls, currents, tides, the wind, solar heat, etc.; and third, the electro-chemical decomposition of cheap or refuse substances in the voltaic cell. To the electrical student the last is the most inviting and equally the most promising in the possibilities which it offers."—*The Voltaic Cell:* PARK BENJAMIN

What constitutes a voltaic cell.

THE voltaic cell consists of the combination of two different metals, or a metal and some substance like carbon or graphite, which, suitably dipped in a liquid, and connected outside the liquid by means of an electrical conductor, will produce a current of electricity. For example, if a plate of copper and a plate of zinc be placed in a glass jar containing dilute sulphuric acid, say one part of sulphuric acid diluted with ten parts of water, and be connected with conducting wires, as shown in Fig. 120, the combination will form a voltaic cell, and a current will flow in the direction indicated by the arrows. Here the two different metals, *i.e.*, copper and zinc, form what is called a voltaic pair or couple. Each of the substances in a voltaic couple is called an element. A great many different substances are capable of acting together as voltaic couples. These couples, however, generally consist of two different

Voltaic couples may be formed of different solids, liquids, or gases.

metals, but may consist of a metal and a substance like carbon, or of two different liquids, or even of two different gases.

Electrolyte. The liquid in which a voltaic couple is dipped is called the electrolyte. In order for any liquid to act as an electrolyte, it must possess the power of conducting electricity, and of being decomposed or broken up into its constituent parts by the electricity. **Positive and negative plates or elements.** The different elements of a voltaic couple are sometimes called the plates. There are always two plates in a voltaic cell; viz., the positive and the negative plate. The ends of the plates that project beyond the electrolyte are called the poles or electrodes of the cell, the positive pole or electrode being

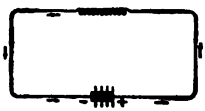


FIG. 121.—Current strength in an electric circuit. Note here the manner in which an electric source, in this case four voltaic cells, is conventionally represented by groups of vertical lines of unequal length.

Poles or electrodes of voltaic cell. the pole from which the current leaves the cell, or flows out of it, while the negative pole or electrode is the pole at which the current returns to the cell. It is often very convenient to represent a voltaic cell or any other electric source—*i.e.*, any device for producing E.M.F., and therefore setting electricity in motion—by two vertical lines of unequal length, as are shown in Fig. 121. Here each two vertical lines may be taken as representing the two plates in a voltaic cell. We cannot see an electric current or flux any more than we can magnetic flux. It is therefore convenient to make a convention as to the direction in which the current is assumed to flow, as is done in the case of magnetism. Just as, in mag-

netism, the flux is assumed to come out of the north pole of the magnet, and, after flowing through the space lying outside the magnet, to return to the magnet at its south pole, so in electricity, the electric current is assumed to leave the electric source at its positive pole, or electrode, and, after having passed through the conducting path provided for it outside the source, to re-enter the source at its negative pole, or electrode. Consequently, in this figure, we assume that the electricity leaves the source, *i.e.* the voltaic cell, at its positive electrode, and returns to it at its negative electrode, after it has passed through the conducting circuit provided for it outside the source.

Referring now again to the right-hand side of Fig. 120, it will be seen, that although the electric current leaves the terminals or electrodes of a voltaic cell at its positive electrode or terminal, which, in this case, will be the copper terminal of the copper-zinc couple there represented, and returns to the cell at its negative electrode, viz. the zinc terminal, that, during its passage through the electrolyte in the cell it necessarily leaves the zinc plate, and, after flowing through the liquid, re-enters the copper plate. Consequently, in accordance with the convention above referred to, that part of the zinc plate which is below the surface of the liquid of the electrolyte must be positive. No little confusion sometimes arises by regarding the zinc as the positive plate and the copper as the negative plate. Strictly speaking, these terms are correct in accordance with the above convention. It may, perhaps, be preferable to speak of the positive plates as possessing the same polarities as the conductors connected with them. We shall, therefore, hereafter, unless it is otherwise specifically stated, call, in the case of a zinc-

Confusion as to meaning of positive and negative plates.

copper couple, the copper the positive plate, and the zinc the negative plate. In any voltaic couple, during the production of the current, one of the plates only is acted on; for example, in the zinc-copper couple immersed in dilute sulphuric acid, the zinc plate only is acted on. In all cases that element of a voltaic couple which is acted on during the production of the current will hereafter be called its negative plate and the other its positive plate.

The circuit of a voltaic cell is said to be open or broken when no conducting path is provided outside the cell. The circuit is said to be completed, or made, when a continuous unbroken conducting path is provided.

Local action.

During action, that is while the voltaic cell is producing current, the negative plate, as we have seen, is slowly dissolved in the electrolyte. In the case of zinc, if this plate were made of chemically pure metal, no action would take place when the circuit was open or broken. In point of fact, however, owing to the presence of impurities in the commercial zinc employed in all voltaic cells, a wasteful local action will take place and the zinc will be dissolved, as will be shown by the appearance of bubbles of gas that are given off from the surface. In order to prevent this local action the zinc must be amalgamated, or covered with a thin coating or layer of amalgam.

Amalgamation of zinc plate.

This is accomplished by dipping the zinc plate into a solution of sulphuric acid and water, throwing a few drops of mercury on the zinc, and then rubbing its surface with a cloth. By these means the zinc becomes coated with a bright metallic surface of mercury. Amalgamated zinc, even though impure, is not acted on by the electrolyte when the voltaic cell is on open circuit.

As already stated, gaseous substances are capable of being employed as the elements of a voltaic cell. Now when the circuit of a voltaic cell is closed, although a chemical action takes place on the zinc or negative plate, yet the hydrogen, instead of being given off at the zinc plate, appears at the surface of the copper or positive plate. Consequently, the copper plate becomes covered with bubbles of hydrogen gas. But hydrogen gas is positive to zinc. A tendency therefore exists to produce an electromotive force that is so directed as to send an electric current through the liquid of the cell from the hydrogen-covered copper plate to the zinc, or in the opposite direction to that through which the current ordinarily passes. There thus results a falling off in the strength of the current delivered by the cell. Moreover, this decrease in the current strength is aided by the fact that the gas covering the copper plate interposes a high electric resistance to the passage of the current, and, therefore, cuts down its strength.

Effect of hydrogen on copper plate on the current strength of cells.

The accumulation of hydrogen gas on the surface of the copper plate is called polarization. In some cases the polarization takes place so rapidly that in a few minutes, or even after a few seconds, the current strength becomes too feeble to permit the cell to properly act. For example, if an electro-magnetic bell be placed in the circuit of an ordinary zinc-copper couple immersed in sulphuric acid, the bell will at first sound vigorously, but, on account of the rapid polarization that takes place, the sound will become fainter and fainter, and, after a few moments, will entirely cease.

Polarization of the voltaic cell.

There are several ways by which the bad effects of polarization may be avoided. Briefly, these may be divided into three classes; viz., mechanical, chem-

ical, and electro-chemical. The gas may be removed mechanically, as, for example, by directing a stream of air against the plate so as to brush off the gas that collects; or by roughening the surfaces of the plate, so as to cover it with points. Here the gas, collecting in greater quantities at the points, is able to pass mechanically off the surfaces. A more effective way is to remove the gas by chemical means, that is, to dip the plate on which the gas accumulates into some chemical solution, such as nitric or chromic acid, which possesses the power of entering into combination with hydrogen gas, and so removing it. But what is a still better way is the method called the electro-chemical method, in which such electrolytes are employed that the substance which collects on the plate aids rather than retards the action of the cell; for example, in a copper-zinc couple, instead of hydrogen being deposited on the copper plate, a film of electrically deposited copper is deposited. In such cells the bad effects of polarization are thus entirely avoided.

How the polarization of a voltaic cell may be lessened.

How polarization may be entirely avoided.

The mechanical avoidance, and in some cases the chemical avoidance, of the polarization of voltaic cells, is so inefficient that the cell soon becomes incapable of continuously supplying electrical currents of sufficient strength to properly operate the different devices with which it is connected. Such cells are, therefore, only suitable for giving occasional currents, such as are required for the ringing of bells, the operation of signals, or for use in telephony or telegraphy. Such cells are called open-circuit cells, in order to distinguish them from constant or closed-circuit cells, which are able to remain continuously on closed circuit. In all practical open-circuit cells, however, the cells perfectly recover their activity or depolarize, if left for a time on open circuit.

Closed-circuited and open-circuited voltaic cells

In any voltaic cell the current strength the cell is able to furnish, in a given time, will, of course, depend on the electrical resistance which the cell itself possesses. If this be great, the amount of current the cell can pass through a circuit outside itself will also necessarily be small. Consequently, a good voltaic cell should possess a small electric resistance. Since local action produces a useless current, a good voltaic cell should possess but little local action. The substances of which the couples are composed should not be of an expensive character. For some purposes, the current strength need not be very great. For other purposes, the current strength is of more importance, so that the resistance of a cell is a matter that should be carefully looked after. In all cases where large currents are required the resistance must necessarily be small. No single-fluid cell possesses all these characteristics. It is for this reason that a very great number of different voltaic cells have been invented. All these, however, may be divided into two classes; viz., single-fluid voltaic cells and double-fluid voltaic cells.

Some requisites of voltaic cells.

Why so many different voltaic cells have been invented.

A very common but excellent form of a single-fluid voltaic cell is that called the bichromate cell, from the fact that its electrolyte consists of a solution of bichromate of potash dissolved in water containing sulphuric acid. In this cell the voltaic couple consists of a plate of zinc and a plate of carbon. Since the bichromate cell is generally employed for producing large currents, in order to lessen its electrical resistance both surfaces of the zinc are employed, by placing carbon plates on each side of the zinc plate, as shown in Fig. 122. This arrangement doubles the area of cross-section of the electrolyte, and this, as we have already seen, reduces its electrical resistance one-half. The electrodes or ter-

The bichromate voltaic cell.

minals of the cell are furnished with what are called binding posts. These consist of small cylindrical posts of brass provided with openings for the insertion of the conducting wires, which are then clamped into the post by means of small screws. When the cell is not furnishing current the zinc plate is raised out of the electrolyte. This cell causes an electromotive force of, approximately, 1.96 volts.

The red exciting liquid employed in this cell is made by dissolving one pound of crystals of bichro-

FIG. 122.—The Bichromate Voltaic Cell. The zinc plate may be raised from the liquid, when the cell is not in use, by raising the rod shown between the two binding posts on the top of the cell.

Why the red color of the exciting liquid in the bichromate cells turns green.

mate of potash in ten pounds of water, and then slowly adding $2\frac{1}{2}$ pounds of sulphuric acid. It is necessary to add the sulphuric acid slowly, since sulphuric acid mixed with water heats the liquid, and if added all at once the heat liberated may break the glass vessel. The red liquid rapidly changes to a green color on being used, owing to the decomposition that takes place at the action of the cell. Crystals of chrome alum are frequently deposited on the bottom of the jar. This substance is formed during the action of the cell. The red exciting liquid is very

poisonous, and should be kept out of the way of ignorant people.

Another form of single-fluid voltaic cell is called the Smee cell. This, as shown in Fig. 122A, is composed of a voltaic couple, of zinc and silver dipped into sulphuric acid diluted with water. In order to decrease the polarization the surface of the silver plate is either roughened or is covered with a coating of finely divided platinum called platinum black. This cell was formerly employed in electro- **The Smee voltaic cell.**

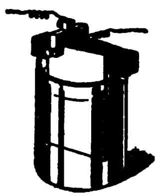


Fig. 122A.—The Smee Voltaic Cell. Note here that the zinc element, the outer plates, is placed on both sides of the silver plate, thus decreasing the resistance of the cell.

plating, or depositing one metal on the surface of another by means of an electric current. The Smee cell gives an electro-motive force of about .65 volts.

Sometimes, in single-fluid voltaic cells, in order to decrease the bad effects of polarization, the surface of the positive plate is enlarged. A cell of this type is shown in Fig. 123, where the negative plate consists of a single zinc rod, and the positive plate is formed by a number of carbon rods surrounding the zinc rod. The electrolyte employed is a solution of sal-ammoniac, or ammonium chloride. This cell belongs to the open-circuit type of cell, and is employed in cases where a small current is required at considerable intervals only, such as for ringing

bells, sounding alarms, setting signals, etc. In such cases long rests between the times of using the cell give it abundant opportunity for depolarizing.

Use of porous cups in voltaic cells

In double-fluid cells, as the name indicates, two separate fluids are employed, in which the elements are separately dipped. In order to prevent these fluids from mixing, they are either placed in vessels of unglazed earthenware, called porous cups or cells, or the liquids are kept apart by means of differences in their density or gravity.

FIG. 123.—A form of a zinc-carbon open-circuited voltaic cell in which the area of the carbon element is greatly increased.

The Bunsen voltaic cell.

There are a great variety of double-fluid voltaic cells. A common form is seen in the Bunsen cell, so named after the celebrated German chemist, who invented it in 1842. The Bunsen cell consists of a voltaic couple of carbon and zinc, immersed respectively in strong nitric acid, and in dilute sulphuric acid. The nitric acid is placed inside a porous cell, in which the carbon, in the shape of a solid cylinder, is placed, as shown in Fig. 124. The zinc is in the form of a hollow cylinder, and is placed outside the porous cell in a jar containing the dilute sulphuric acid. The terminal connected with the carbon is the positive terminal, and that connected with the

zinc is the negative terminal. This cell gives an electro-motive force of 1.96 volts. The Bunsen cell is a modified form of a cell called the Grove cell, invented by Grove in 1839, in which, instead of a cylinder of carbon, a plate of metallic platinum was employed.

The Grove voltaic cell.

In 1836, Prof. J. F. Daniell, of London, England, invented a form of voltaic cell which was a great improvement on pre-existing forms, in that, unlike any preceding cells, it absolutely prevented the

Daniell's great invention of the electro-chemical method of avoiding polarization

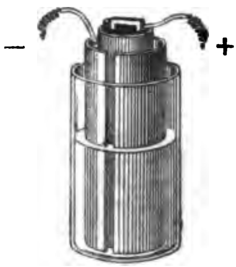


Fig. 124.—Bunsen's Voltaic Cell. Here the zinc is placed in the dilute sulphuric acid in the outer vessel, and the carbon cylinder in the porous cell containing nitric acid.

deposition of hydrogen on the copper plate of a zinc-copper couple. Daniell accomplished this much-to-be-desired result by dipping the copper plate in a solution of copper sulphate or blue vitriol, so that, instead of the hydrogen gas being deposited on the surface of the copper plate, the hydrogen acting on the copper sulphate solution surrounding the copper plate coated it with an adherent film of metallic copper. In other words, Daniell invented the electro-chemical method of preventing the polarization. This method is by far the most efficient known for accomplishing this result. The Daniell cell was the first voltaic cell that was capable of producing a constant current or forming a true closed-circuit cell.

Effect of surrounding copper plate by solution of copper sulphate.

This cell marked such an era in science that, although to-day it is but little employed in the exact form in which it was invented, yet we will describe it, especially as the general principles on which it is constructed are the same as those of the cell which has supplanted it.

Daniell's constant voltaic cell.

The general appearance of a Daniell constant voltaic cell is shown in Fig. 125. It consists of a zinc-copper couple, the elements of which are dipped respectively in sulphuric acid diluted with water, and in a saturated solution of copper sulphate in water; that is, a solution in which the water has dissolved as great an amount of crystals of copper sulphate as it

FIG. 125.—Daniell's Constant Voltaic Cell. Note the upper surface of the crystals of copper sulphate in the copper cylinder.

is capable of dissolving. The copper element was made in the form of a hollow cylinder provided with a perforated copper basket placed near the top. This basket was filled with crystals of blue stone or copper sulphate, so as to keep up the strength of the copper sulphate solution during the action of the cell. The copper cylinder was placed inside a porous cell filled with a saturated solution of copper sulphate. The zinc, in the shape of a hollow cylinder surrounding the porous cell, was placed in a glass vessel filled with sulphuric acid diluted with water. The electro-motive force of this cell is 1.072 volts.

BENJAMIN FRANKLIN'S KITE EXPERIMENT—IDENTITY OF ELECTRICITY WITH LIGHTNING

It is not difficult to understand why a Daniell cell is capable of supplying a constant electric current, since the troubles arising in previously existing cells, owing to the unsatisfactory methods employed for avoiding polarization, are here entirely removed. In the Daniell cell the hydrogen, which would otherwise be liberated at the surface of the copper plate, in passing through the solution of copper sulphate surrounding the copper plate, decomposes it, depositing metallic copper on the surface of the copper plate. At the same time, as a result of this decomposition, sulphuric acid is liberated, and passing through the porous cell into the dilute sulphuric acid in the outer cell, serves to maintain its strength as it becomes weakened by dissolving the zinc. It is true that the solution of copper sulphate in the inner cell becomes weakened by reason of the copper sulphate that has been removed from it by decomposition by the hydrogen; but this loss is at once made up by the liquid dissolving sufficient of the crystals of copper sulphate in the perforated copper basket to keep the solution saturated. As long, therefore, as there is any zinc to be acted on, and any crystals of copper sulphate in the copper basket to be dissolved, the Daniell cell will continue to supply a current of constant strength to any circuit with which it is connected.

Why the Daniell voltaic cell gives an electric current of unvarying or constant strength.

The invention of the Daniell cell is properly regarded as of great importance to electric science. It serves as an example of the manner in which several great inventions often go hand in hand. As soon as scientific men discovered that the electric current is transmitted almost instantly through good conductors, many different suggestions were made as to the possibility of telegraphic communication. Before, however, any of the ordinary systems of telegraphy

The effects of the invention of the Daniell cell on electric science.

now in use could become commercial possibilities, two other great inventions were necessary; viz., that of the electro-magnet, and that of an electric source capable of supplying for a practically indefinite time an electric current of approximately constant strength. It was the invention by Daniell that supplied this latter want, and for this reason alone it would be proper to regard his invention as of great advantage to electric science. But in addition to this, by placing for the first time, in the hands of scientific men, a means for readily producing an electric current of constant strength, it permitted other inventions to be made which were of equal importance to the advance of electric science. Prominent among these is that of the ability of the electric current to decompose chemical substances. The principles of this latter discovery will be treated hereafter.

Daniell describes the construction of his voltaic cell in a letter to Faraday, which was published in the "Philosophical Transactions" for 1836. The following quotation was taken from the "Annals of Electricity," published in London, in 1837:

Daniell's description of his constant voltaic cell.

"In the construction of this battery, I have availed myself of the power of reducing the surface of the generating plates to a minimum, the effective surface of one of the amalgamated zinc rods being less than ten square inches, while the internal surface of the copper cylinder to which it is opposed is nearly seventy-two inches. My principal objects have been to remove out of the circuit the oxide of zinc, which has been proved to be so injurious to the action of the common battery, as fast as the solution is formed, and to absorb the hydrogen evolved upon the copper without the precipitation of any substance which might deteriorate the latter.

"'The first is completely effected by the suspension of the rod in the interior membranous cell, into which the fresh acidulated water is allowed slowly to drop from a funnel suspended over it, and the aperture of which is adjusted for the purpose; while the heavier solution of the oxide is withdrawn from the bottom at an equal rate by the syphon tube. When both the exterior and interior cavities of the cell were charged with the same diluted acid, and connection made between the zinc and copper by means of a fine platinum wire 1-200 of an inch in diameter, I found that the wire became red hot, and that the wet membrane presented no obstruction to the passage of the current.

"The second object is attained by charging the exterior space surrounding the membrane with a saturated solution of sulphate of copper instead of diluted acid; upon completing the circuit the current passed freely through this solution; no hydrogen made its appearance upon the conducting plate, but a beautiful pink coating of pure copper was precipitated upon it, and thus perpetually renewed its surface. How polarization is avoided.

"When the whole battery was properly arranged and charged in this manner, no evolution of gas took place from the generating or conducting plates, either before or after the connections were complete; but when a voltameter was included in the circuit, its action was found to be very energetic. It was also much more steady and permanent than that of the ordinary battery; but still there was a gradual, but very slow decline, which I traced at length to the weakening of the saline solution by the precipitation of the copper, and the consequent decline of its conducting power. Action of Daniell battery.

"To obviate this defect, I suspended some solid sulphate of copper in small muslin bags, which just

How the copper sulphate solution is kept saturated.

dipped below the surface of the solution in the cylinders, which, gradually dissolving as the precipitation proceeded, kept it in a state of saturation. This expedient fully answered the purpose, and I found the current perfectly steady for six hours together. This arrangement I have since improved by placing the salt on a perforated colander of copper fixed to the upper collar."

Difficulty in actual use of the Daniell cell

Daniell's voltaic cell was found, in practice, to give considerable trouble from the metallic copper being deposited not only over the surface of the copper cylinder, but also, at times, over the surface of the porous cell, thus closing some of the pores and greatly increasing the resistance of the cell. Moreover, the use of the unglazed earthenware to keep the two fluids apart, is open to the objection of greatly increasing the resistance of the cell. In 1855, Varley removed both of these objections, by doing away entirely with the porous jar. This he effected by keeping the solutions of copper sulphate and dilute sulphuric acid separate from each other by means of their different densities. Varley's cell is called the gravity cell, and has practically entirely replaced Daniell's original form.

Varley employs differences of density to keep the two liquids separated.

Varley's gravity voltaic cell.

The form generally given to the gravity voltaic cell is shown in Fig. 126. Here the two elements are placed one over the other, the copper element at the bottom of the glass jar, where it is surrounded by crystals of copper sulphate, while the zinc plate is suspended near the top of the jar, where it is surrounded by a solution of zinc sulphate or white vitriol. This latter solution is so much lighter than the saturated solution of copper sulphate that it will float on its surface as oil floats on water.

In starting a gravity cell it is customary to place

the two plates in their proper positions, one above the other, filling the jar with water, and throwing in a handful of crystals of copper sulphate. These, covering the bottom of the plate, soon dissolve and fill the bottom of the jar with a saturated solution of copper sulphate, care being taken to add a sufficient amount of crystals of copper sulphate to keep a quantity of undissolved crystals at the bottom of the jar. If the cell is then placed on short circuit for a while, it will soon put itself in running order. The time required to do this, however, is much shortened by adding a small quantity of solution of zinc sulphate

How a gravity voltaic cell is set up or started.

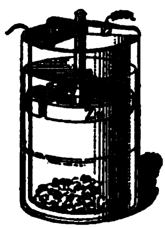


FIG. 126.—The Gravity Voltaic Cell. Note the relative position of the plates, the zinc plate being above the copper plate.

or a little sulphuric acid to the water. Under these circumstances the cell is almost immediately ready for action.

The gravity voltaic cell must be kept in constant action in order to prevent the two liquids from mixing by diffusion, a process by means of which heavy liquids can rise through light ones and light liquids descend through heavy ones, until they are thoroughly intermixed. While a gravity cell is producing current, the copper sulphate is changed too rapidly into zinc sulphate to be able to diffuse throughout the zinc sulphate solution. A gravity cell in proper action shows a sharply marked level

The gravity voltaic cell must be kept on closed circuits in order to avoid diffusion or mixing of the two liquids.

surface of blue copper sulphate solution, on the top of which rests the clear solution of zinc sulphate.

Use of solid depolarizer

In some voltaic cells, where chemical action is employed to prevent polarization, instead of using an additional fluid to oxidize the hydrogen that tends to be liberated at the surface of the plate connected with the positive electrode, some solid depolarizer, such as black oxide of manganese, or, as it is called in chemistry, binoxide of manganese, is employed. Oxide of copper, or, as it is called in chemistry, copper oxide, is also sometimes employed for the same purpose.

The Leclanché voltaic cell is an example of a well-

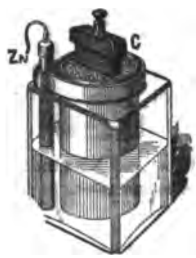


FIG. 127.—The Leclanché Voltaic Cell. The top or cover is removed from the carbon element in order to show its construction.

Leclanché voltaic cell.

known form of cell employing a solid depolarizer. A Leclanché cell is shown in Fig. 127. Here a zinc-carbon couple is employed. The carbon element consists of a carbon plate placed in a porous cell, and surrounded by a mass of thoroughly mixed, finely divided carbon and black oxide of manganese. This mass is thoroughly packed into the porous cell, so as to ensure good electrical contact with the carbon. By these means we obtain an extended surface of carbon closely surrounded by a solid depolarizer of black oxide of manganese. The zinc is placed in

the form of a small rod in the outer cell. The Leclanché cell gives an electro-motive force of 1.74 volts.

The Leclanché cell rapidly polarizes, and can not, therefore, be employed for any electric work that requires a continued current. For ringing electric bells, setting signals, or for similar work that requires only a momentary current, it answers excellently, and is very extensively employed, since the comparatively long intervals of rest, which the cell has between the times when it furnishes current, enable it to thoroughly depolarize.

Where Leclanché cells are employed.

J. A. Barrett, in an article in the "Electrical World," of February, 1890, calls attention to the fact that in a Leclanché cell, the life of the negative element is commonly supposed to be determined by the amount of black oxide of manganese associated with the carbon plate. He claims that long before the active oxygen in this manganese is exhausted, the element is generally thrown away as useless, chiefly because the various compounds of zinc, accumulated in the porous cell, are insoluble in the scanty liquid existing therein, and have therefore caused an increased resistance of the cell. It is, therefore, important to bear in mind that, frequently, an apparently exhausted Leclanché cell can be made to continue to furnish a working current by carefully washing it in dilute muriatic or hydrochloric acid, and then setting up the cell with a fresh charge of sal-ammoniac. In other words, employ at the outset a larger containing glass jar, in which, consequently, a greater amount of liquid can be placed, and there will result an increased life of the cell.

Barrett on the extension of the life of a Leclanché voltaic cell.

Another form of voltaic cell employing a solid de-

The Edison-Lalande voltaic cell.

polarizer is the Edison-Lalande cell. Such a cell is shown in Fig. 128. It consists of a zinc-copper couple. The copper is covered with a layer of compressed copper oxide. The zinc is generally placed in the shape of two plates on each side of the copper plate. The electrolyte is a solution of caustic potash or caustic soda, dissolved in water. In order to prevent the carbonic acid of the atmosphere from entering into combination with the potash or soda, which would thus injuriously affect the action of the cell, a layer of paraffine oil is allowed to float on the upper surface of the alkaline solution. During

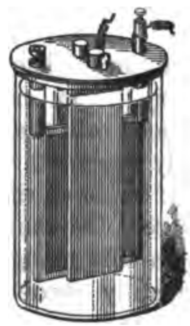


FIG. 128.—The Edison-Lalande Voltaic Cell.

ing action the zinc is dissolved in the alkaline liquid, and the copper oxide is reduced to metallic copper by the liberated hydrogen. The electro-motive force of this cell is about 2-3 of a volt.

Standard voltaic cells

When a voltaic cell is constructed so as to give a constant electro-motive force, it is frequently employed as a standard, by means of which the value of an unknown electro-motive force can be readily determined. When so employed, such cells are called standard voltaic cells. There are several well-known forms of standard voltaic cells, but a description of two of the commonest forms will suffice. One of the

most accurate is, perhaps, Rayleigh's modification of Clarke's standard voltaic cell. It consists of a zinc-mercury couple. The positive electrode is connected with a mass of pure mercury, Hg, covered by a paste, made by boiling mercurous sulphate in a saturated solution of zinc sulphate. The negative pole or electrode consists of a piece of pure zinc, Zn, resting on this paste. Since no hydrogen is liberated during the action of this cell, it can be tightly sealed in a glass tube. The general arrangement of a Rayleigh's standard cell is shown in Fig. 129. The mercury is

Rayleigh's modification of Clarke's standard voltaic cell

FIG. 129.—Rayleigh's modification of Clarke's Standard Voltaic Cell.

placed at the bottom of the glass tube, and on its upper surface is placed a paste of mercurous sulphate mixed with a sufficient quantity of solution of zinc sulphate to render it semi-fluid. The zinc is attached to the upper part of the tube, and immersed in the same fluid paste. Silver wires connecting the mercury and the zinc pass respectively through the bottom and the top of the tube, and form the electrodes or terminals of the cell. This cell gives an electro-motive force of, approximately, 1.436 volts. The value of this electro-motive force, however, changes with the temperature, so that corrections

must be made for the different temperatures at which the cell is employed as a standard.

Fleming's standard voltaic cell.

A simpler form of a standard voltaic cell, known as Fleming's standard cell, is shown in Fig. 130. This is a modified form of Daniell's cell, so arranged that rods of pure zinc and copper can be immersed

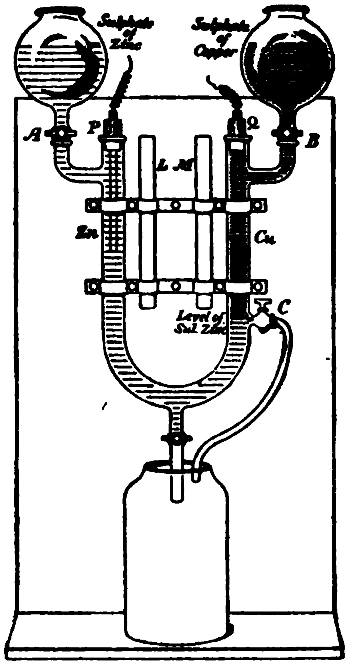


FIG. 130.—Fleming's Standard Voltaic Cell. Note that this is merely a Daniell's cell, so arranged as to obtain the E.M.F. resulting from a zinc-copper couple immersed in solutions of zinc and copper sulphate respectively.

respectively in pure solutions of zinc sulphate and copper sulphate. The zinc and copper elements in the shape of rods, are placed at P and Q, respectively, in the branches of a U-shaped glass tube connected, as shown, with reservoirs containing solutions of zinc sulphate and copper sulphate. The

solution of copper sulphate is diluted with sufficient water to render it less dense than the saturated solution of zinc sulphate employed. The operation of the cell is as follows:

The tap, A, is open, and the whole U-shaped tube is filled with a dense solution of zinc sulphate. The zinc rod is then inserted, and the rubber cork connected with it tightly inserted in the tube. A tap at C is now opened, and the liquid runs out of the right-hand tube, but remains in the left-hand tube because it is tightly closed. As the level sinks in the right-hand tube, the tap, B, is slowly opened, and the copper sulphate allowed to flow gently into the right-hand tube. With care this can be effected so that a sharp line of separation marks the two solutions. When this is obtained, the copper rod is inserted, and the cork, Q, connected with it, tightly fitted in the tube. In this manner two chemically pure rods of zinc and copper, immersed respectively in pure solutions of zinc sulphate and copper sulphate, can be obtained, so that the electro-motive force the cell produces at different times is constant, provided allowances are made for the temperature. Method of using Fleming's standard voltaic cell.

Great care is necessary to keep the surfaces of the zinc and the copper rods clean. Chemically pure zinc only is used, and its surface is kept clean by careful polishing, while the copper rod has, at frequent intervals, a fresh coating of metallic copper deposited on it by chemical means. The electromotive force of this cell is 1.074 volts. The electromotive force decreases as the temperature rises, the decrease being about .08 per cent for each degree of the Centigrade scale; therefore, a correction must be made for the temperature at which the cell is used. E.M.F. of Fleming's standard.

Voltaic cells or batteries *versus* dynamo-electric machines.

Attempts have been made to so improve the efficiency and economy of voltaic cells as to render it possible for them to furnish electric current cheaper than can a dynamo electric machine driven by a steam engine. A little consideration, however, will show the improbability of success in such attempts. In the ordinary voltaic cell the energy required to maintain the electric current is derived from the burning or consumption of the zinc in the sulphuric acid or chromic acid in which it is dipped. The chemical combination or consumption of the zinc in these acids is similar to the burning or consumption of the carbon of the coal in the air. Now it can be shown that the burning of a ton of zinc in acid will liberate only about one-sixth the energy liberated by the burning of a ton of coal in air. But since zinc is very much more expensive than coal, and sulphuric acid or chromic acid very much dearer than air, it will be seen that the voltaic cell, as at present constructed, can never be able to compete commercially, in the production of electricity, with a steam-driven dynamo.

CHAPTER XXIV

OHM'S LAW—VOLTAIC BATTERIES

"When a current is produced in a conductor by an E.M.F., the ratio of the E.M.F. to the current is independent of the strength of the current, and is called the resistance of the conductor."—DR. G. S. OHM, 1827

THE comparatively low electro-motive forces produced by voltaic cells frequently render it necessary to combine them in various ways, so that a number of separate cells can act as a single cell. Such combinations, as already stated, are termed voltaic batteries. Before entering into a study of voltaic batteries, it will be necessary to give some little attention to a very important law, known in electrical science as Ohm's law.

Voltaic batteries.

In 1827, Dr. G. S. Ohm, of Germany, made a remarkable mathematical discovery regarding the law in accordance with which the amount of electricity that flows through a circuit in a given time, can be readily calculated. This law is of great importance to electric science. It is by no means difficult to understand it if some little thought is given to the subject. We shall, therefore, endeavor to make it clear, since its understanding renders many things in electricity easy to be comprehended.

Ohm's law, discovery of in 1827.

As we have seen, it is not electricity, but an electro-motive force, that is produced by any electric source. This E.M.F. sets electricity in motion. We

E.M.F.'s not electricity produced by electric sources.

have also seen that in any conducting path or circuit, even when such path is composed of good conductors of electricity, there is always an electric resistance offered to the passage or flow of a current of electricity. Now, Ohm's law explains how it is possible, in a simple manner, to calculate the value of the current or flow which will take place in any circuit, provided we know the E.M.F. that is acting on that circuit, and the electric resistance that opposes the flow of electricity; for, if we simply divide the value of the E. M. F. by the electric resistance we obtain the value of the resulting current.

Ohm's law and the practical electric units.

We have also given some little account of the practical electrical units, and have defined the following: viz., the volt, or the practical unit of E.M.F.; the ampère, or the practical unit of electric current; the ohm, or the practical unit of electric resistance; the coulomb, or the practical unit of electric quantity; and the farad, or the practical unit of electric capacity.

Concise statement of Ohm's law.

Now, bearing in mind the meanings and values of these various units, Ohm's law may be simply stated as follows: That when the electric current continues to flow in one and the same direction, and does not alternate, or rapidly change its direction, the strength of the current that flows in the circuit, expressed in ampères, is equal to the E.M.F. acting on that circuit, expressed in volts, divided by the electric resistance of that circuit, expressed in ohms; or, more simply, the ampères in any circuit are equal to the volts divided by the ohms. This is sometimes, for the sake of convenience, expressed in the form of a simple equation, as follows:

$$\text{ampères} = \frac{\text{volts}}{\text{ohms}};$$

which is simply a mathematical way of expressing the fact that the ampères are equal to the volts divided by the ohms.

It is easy, from this simple expression, to see the relations existing between the different practical electric units; for example, an ampère is equal to the current that will pass through an electric circuit whose resistance is one ohm, when acted on by an electro-motive force of one volt. Similarly, a volt is the electro-motive force required to act on a circuit whose resistance is one ohm, in order to pass one ampère of current through it; and, similarly, an ohm is such a resistance as will limit the flow of electricity through a circuit to one ampère, when such a circuit is acted on by an electro-motive force of one volt.

Relations between practical electric units disclosed by Ohm's law.

The flow of electricity through a conductor under the influence of an E.M.F., and against the resistance of the conductor, is analogous to the flow of water or other liquid through a pipe from a reservoir. Here the reservoir is analogous to the electric source. If the water flows out of the reservoir it is necessary that some pressure act on it. If an opening be made in the side of a reservoir filled with water, say near the bottom, the water will escape and flow out of the opening by reason of the pressure. The pressure, which sets the water in motion, may be called the water-motive force, that is, the water moving force. The quantity of water which escapes in a given time will depend on the amount of this pressure, and on the size of the opening through which water escapes; or, what amounts to the same thing, on the resistance offered to its escape or flow from the reservoir. We may say, in this case, that the value of the water current can be determined by dividing the water-

Analogies between flow of water and flow of electricity.

Water-motive force and electro-motive force.

motive force by the resistance offered to its escape, provided these values are properly expressed. The current of water which flows through the opening can be expressed by the amount or quantity which passes through it in a given time, say in one second.

Resistance to flow in passage of water and electricity.

Now, in the case of the electric flow, the electric pressure, or the electro-motive force, which sets the electricity in motion, corresponds to the pressure, or water-motive force, which sets the water in motion. The resistance which opposes the motion of the electricity through a conductor varies with its length and area of cross-section. The resistance which opposes the flow of water through a pipe varies with the size of the pipe, and the character of its construction, as to whether the inside be smooth or roughened, etc. In the case of the electric flow, a greater amount of electricity per second will pass through a copper wire of a given area of cross-section and length, than will flow through an iron wire of equal cross-section and length. The same thing is true in the case of a water flow: more liquid will run out of an opening when the resistances tending to oppose such flow are small, than will escape from an equally large opening under circumstances where the resistances tending to oppose its passage are great.

Circumstances affecting value of the flow.

The ampère equal to the passage of one coulomb per second.

Just as, in electricity, the ampère may be regarded as the rate of flow, or the rate at which electricity passes through an electric circuit, so in a water circuit, the rate of flow of water can be similarly estimated. In the electric circuit we may define the ampère as that current which will transmit electricity at the rate of one coulomb per second; so in a water circuit we may define the unit of current to be a current which will represent the passage of so many cubic feet of water per second.

Electric conductors are generally made in the form of cylindrical wires, that is, wires with circular areas of cross-section. It will not be amiss here to review the three circumstances upon which the resistance of a conductor or a wire depends: viz., on its length, the greater the length, the greater the resistance; on its area of cross-section, the greater the area of cross-section the less the resistance; and on the character of the material of which the wire or material is formed, copper being a much better conductor than iron, and iron a better conductor than lead. For example, if the resistance of a given length of copper wire of a given area of cross-section be 96, then a wire of the same length and area

Circumstances affecting the electric resistance of conductors.

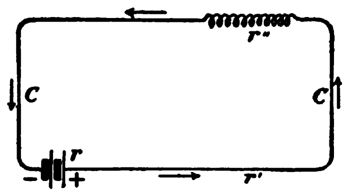


FIG. 131.—Determination of the current strength in an electric curcuit.

of cross-section, if of gold, would be 74; if of soft iron, 16; of platinum, 8; of German silver, 7.5; and of pure mercury, 1.6.

In order to show the application of Ohm's law to a simple case, let us suppose that a certain electro-receptive device—*i.e.*, a device through which current passes, and in which it produces some characteristic effect, such, for example, as heat, light or magnetism—is placed, as shown in Fig. 131, in a circuit connected by means of conducting wires or leads C, C, with an electric source at *r*. Suppose, moreover, that this source has an electro-motive force of three volts, and that the resistance of the source itself is one ohm, that of the conductors one ohm, and that

of the receptive device, r'', one ohm. Then, according to Ohm's law, the current strength passing through such circuit would be equal to

$$\text{ampères} = \frac{\text{volts}}{\text{ohms}} = \frac{3}{1+1+1} = \frac{3}{3} = 1;$$

or the current strength is equal to one ampère. Consequently, the receptive device will be operated by reason of its receiving every second an amount of electricity equal to one coulomb.

We are now ready to see what effect will be produced by joining a number of separate voltaic cells

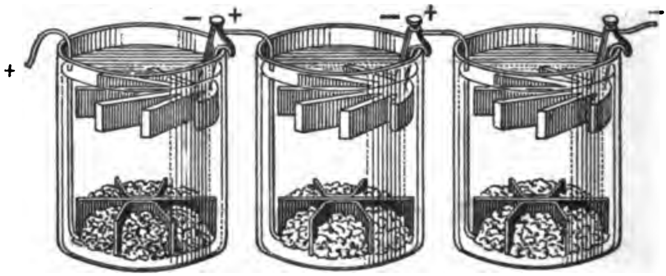


FIG. 132.—Voltaic Battery formed of three series-connected gravity voltaic cells.

into a single cell or battery. Suppose, for example, we desire to increase the strength of the current which can be produced by a number of separate voltaic cells. It is evident that, in order to do this, we must either increase the electro-motive force of the battery, or decrease its resistance. Now, necessarily, the E.M.F. of any voltaic cell does not depend on the size of the plates, but only on the character of the metals or other substances employed in the voltaic couple, as well as on the character of the electrolyte into which these elements are dipped. Consequently, the only way we can increase the E.M.F. of a battery, the character of whose cells has already

Connection of voltaic cells in series.

been determined, is to so join or connect these separate cells that the electro-motive force produced by each may be added. This is done by means of what is generally called connection in series; *i.e.*, to connect the positive, +, or plus pole of one cell with the negative, —, or minus pole of the next cell, the positive pole of this cell with the negative pole of the third cell, and so on with all the cells that are to be joined in the single battery. Such a connection is shown in Fig. 132, where three separate gravity voltaic cells are connected in series. Such a combination forms what is called a series-connected voltaic

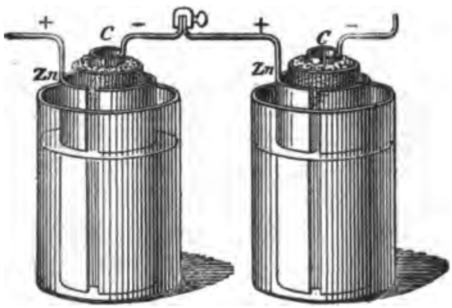


FIG. 133.—Battery of two series-connected Daniell Voltaic Cells. Note that here both the resistance and the E.M.F. of the battery is twice that of a single cell.

battery. Here the terminals or poles of the battery consist of the free or unconnected poles or terminals of the first and the last cell.

The E.M.F. of the preceding series-connected battery will be three times as great as the E.M.F. of any single cell. If, therefore, each cell produces an electro-motive force of say 1.072 volts, the electro-motive force of the battery will be three times as great, or 3.216 volts. The resistance of the battery will, however, be three times the resistance of a single cell, so that, if the resistance of one cell be one ohm, that of the three cells will be three ohms.

The E.M.F. and resistance of series-connected voltaic cells

In Fig. 133, is shown the series-connected battery, consisting of two Daniell's cells, where the zinc of the cell on the right-hand side of the figure is seen connected with the carbon of the cell on the left-hand side, the terminals of the battery being the unconnected ends or terminals; viz., the negative pole being connected with the zinc plate, and the positive pole being connected with the carbon plate.

It will be remembered that Volta's original pile consisted of a series-connected battery, in which many separate cells were so piled on one another as

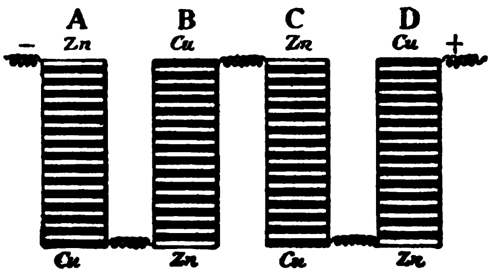


FIG. 133A.—Series-Connected Battery consisting of four separate Series-Connected Batteries.

to obtain a total electro-motive force equal to the E.M.F.'s of all the separate cells added together. Sometimes the series he built up in this way, in order to obtain sufficiently high electro-motive forces, rendered the pile inconveniently high, and also possessed the objectionable feature of causing the liquid with which the disks of cloth were moistened, to be squeezed out by the excessive weight upon them. In such cases he formed the pile in a number of separate piles; for example, in the case shown in Fig. 133A, into four separate piles. Suppose, for example, in this figure, that the piles represented consist of zinc-copper couples, and that the pile A ends at the bottom

Volta's original pile a series-connected battery.

with a copper plate and zinc at the top; that the pile B terminates with zinc at the bottom and copper at the top; that the pile C terminates with zinc at the top and copper at the bottom; and that the pile D terminates with zinc at the bottom and copper at the top. Then, if these four separate piles be connected by conductors, as indicated: viz., a conductor joining A and B at the bottom, B and C at the top, and C and D at the bottom, the four separate piles will form

The series-connection of several series-connected batteries.

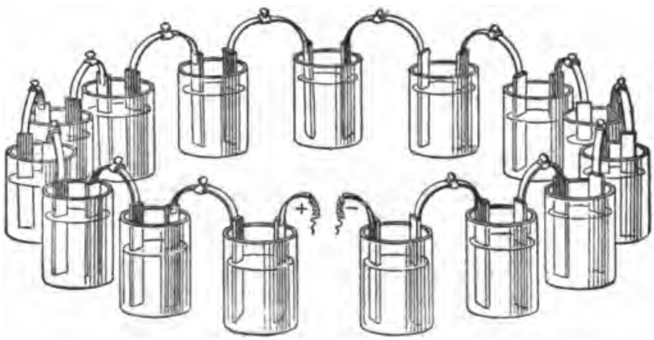


FIG. 134.—Volta's Crown of Cups, or series-connected battery of fifteen separate voltaic cells.

a series-connected battery, of which the free terminals, A and D, will be respectively the negative and the positive poles.

Another form given by Volta to series-connected cells or batteries is shown in Fig. 134. This form was called by Volta, "The crown of cups." Here a number of zinc-copper couples, dipped in dilute sulphuric acid, are connected separately in series by joining the zinc of each cell to the copper of the adjoining cell. As before, the terminals connected with the zinc and copper form respectively the poles or electrodes of the battery.

Volta's crown of cups.

Wollaston's trough battery.

An early form of voltaic battery, called the trough battery, is shown in Fig. 135. This battery, devised by Dr. Wollaston, consists of a number of separate elements of zinc and copper, suitably connected in series, and so mounted in a wooden frame as to be capable of being readily lowered into cups containing the electrolyte. Here the copper is placed on both sides of the zinc plate, so as to lower the resistance of the cell.

But the current supplied by a voltaic cell can also be increased by decreasing the resistance of the cell.

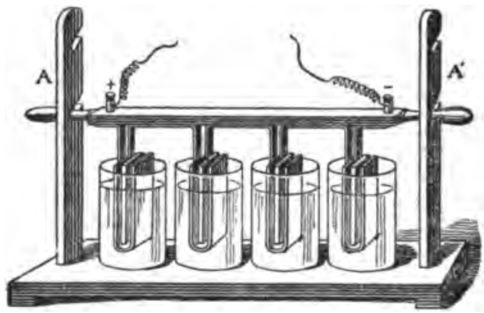


FIG. 135.—Wollaston's Trough Battery of Four Separate Voltaic Cells.

Methods of decreasing the electric resistance of voltaic cells.

This can be done in several ways. The plates may be brought nearer together, thus diminishing the length of the column of liquid through which the current must pass from one plate to the other. This method of decreasing the resistance of a cell can not be carried very far, since the small quantity of liquid existing between the plates will rapidly be weakened by decomposition, so that, unless great care be taken to maintain an active circulation of the electrolyte through the cell, it will result in rapidly decreasing the strength of the current.

Another way to decrease the resistance of a vol-

taic cell is to increase the size of its plates, or, in other words, to increase the area of cross-section, and thus increase the area of cross-section of the mass of liquid between the plates. One method of doing this is to place one of the plates on both sides of the other, as it will be seen has been done by Dr. Wollaston in the plunge battery represented in Fig. 135.

Resistance lessened by increase in effective area of plate.

But the size and the character of the plates of a voltaic cell being once fixed, it is, nevertheless, still possible to so connect them with one another as to increase the area of cross-section of the plates, and thus decrease the resistance of the battery. This is

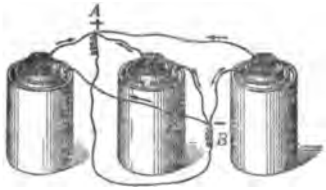


FIG. 136.—Battery of three Multiple-Connected Bunsen Voltaic Cells.

accomplished by what is generally called connection in multiple, or multiple arc. This connection is effected by connecting all the positive plates of a number of separate cells together, so as to form a single positive plate, whose area is equal to the sum of the areas of the separate plates, and similarly connecting all the negative plates together to form a single negative plate, whose area is equal to the sum of all the separate plates. Such a connection is shown in Fig. 136, where three Bunsen cells are connected in multiple arc. Here three separate carbons are connected together to form a single positive pole at A, and the three zincs are similarly joined together to form a negative pole at B. In a multiple-connected voltaic battery the electro-motive force is equal to

Connection of voltaic cells in multiple or multiple-arc batteries.

E.M.F. and resistance of multiple-connected voltaic batteries.

the electro-motive force of a single voltaic cell, but the electric resistance is but one-third the resistance of a single cell; since, here, the effective area of cross-section of the plates is increased threefold, thereby reducing the resistance of the cell to one-third its original resistance. If, therefore, the E.M.F. of the single cell be 1.96 volts and the resistance of each cell be one ohm, then the E.M.F. of the battery will still be 1.96 volts, but the resistance will be only one-third of an ohm.

The difference between the series and the multiple connection of voltaic cells may, perhaps, be bet-

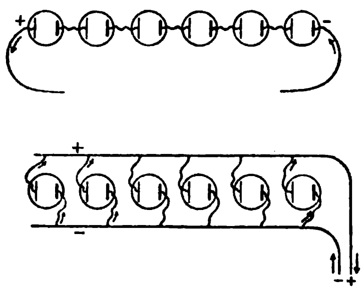


FIG. 137.—Series and Multiple-Connected Voltaic Batteries of Six Separate Cells. Note that in the upper row both the E.M.F. and the resistance of the battery have six times the value of a single cell, while in the lower row the E.M.F. of the battery is the same as that of a single cell, while the resistance is only one-sixth as great.

Series and multiple connection.

ter understood from an inspection of Fig. 137. Here, at the top of the figure are shown six series-connected voltaic cells. By joining the positive pole of each cell to the negative pole of the succeeding cell, the unconnected positive and negative poles at the ends form the poles or electrodes of the series connection. At the bottom of the same figure are represented six separate cells of the same type as the former, connected in multiple arc. Here all the separate positive poles are connected to a single posi-

tive lead or conductor, and all the negative poles similarly connected to another single negative lead or conductor. The series connection was formerly called a connection for intensity, and the multiple connection, a connection for quantity, thus indicating that the former connection gave high electromotive forces, and the latter a greater quantity of current. These terms, however, are now entirely out of use.

It is sometimes necessary to increase both the E.M.F. and the current strength of voltaic cells. This is accomplished by combining both series and multiple connection, as shown in Fig. 138, where the

Series-multiple connected voltaic battery.

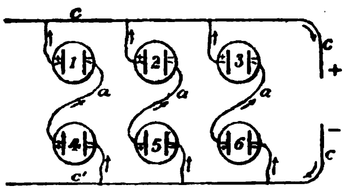


FIG. 138.—Series-Multiple Connected Battery of Six Voltaic Cells.

same six cells shown in Fig. 137, are connected in what is called multiple-series. This connection, as the name indicates, is a connection that partakes both of the series and multiple connection. As an inspection of the figure will show, there are three separate groups formed of two series-connected cells, which are subsequently connected in multiple arc. The E.M.F. of such a battery is twice the E.M.F. of a single cell, but its resistance is only one-third of that of a single cell.

At the present time extensive combinations of a number of separate voltaic cells into series-multiple, or multiple-series batteries, are unnecessary, from the fact that dynamo electric machines are capable of producing powerful electric currents much more

Voltaic batteries replaced by dynamo-electric machines.

readily and far more cheaply than can be done by any voltaic battery now known.

Any other electric sources besides voltaic cells, can be similarly connected in series, multiple, series-multiple, or multiple-series. The same can also be done with electro-receptive devices, such as electric lamps, heaters, etc.

As an example of a large voltaic battery employed during the early times of electrical science, we will briefly describe a type of battery invented by Dr. Callan. This battery gave very powerful effects, but was extremely difficult to keep in good order, and required considerable skill in setting it up. The voltaic couple in each cell consisted of zinc and cast-iron, the zinc being immersed in dilute sulphuric acid, and the cast-iron in concentrated nitric acid, which under certain conditions failed to act on the iron. The following quotation, taken from Noad, will show how powerful such voltaic batteries can be made:

The Callan iron cell.

"A prodigious battery, probably the largest ever made, in which cast-iron was the negative element, was constructed by Dr. Callan (Phil. Mag. Vol. xxxiii. 49). It consisted of 300 cast-iron, water-tight cells, each containing a porous cell and zinc plate 4 inches square; 110 cast-iron cells, each holding a porous cell and zinc plate 6 inches by 4; and 177 cast-iron cells, each containing a porous cell and a zinc plate 6 inches square. The entire battery consisted therefore of 577 voltaic circles, containing 96 square feet of zinc and about 200 square feet of cast-iron. It was charged by pouring into each cast-iron cell a mixture of twelve parts of concentrated nitric acid, and eleven and a half of double-rectified sulphuric acid, and by filling to a proper height each porous cell with dilute nitro-sulphuric acid, consist-

Some effects produced by Callan's voltaic battery.

ing of about five parts of sulphuric acid, two of nitric, and forty-five of water. In charging the entire battery, there were used about fourteen gallons of nitric and sixteen of sulphuric acid.

"The first experiment made with this battery consisted in passing the current through a very large turkey, which was instantly killed, though it afterward appeared that the whole charge did not take place through the body of the bird. In order to give the shock, a piece of tin-foil about four inches square was placed under each wing along the sides of the turkey, which were previously stripped of their feathers, and moistened with dilute acid. The foil was kept in close contact with the skin, by pressing the wings against the sides. The person who held the bird had a very thick cloth between each hand and the wing, in order to save him from the shock. When the discharge took place, the craw of the turkey was burst, and the hay and oats contained within it fell to the ground. Electrocution of turkey.

"When a copper wire in connection with the negative end of the battery was put in contact with a brass ring, connected with the zinc end, a brilliant light was instantly produced. The copper wire was gradually separated from the brass ring, until the arc of light was broken. The greatest length of the arc was about five inches. The length of the arc of light between charcoal points could not be determined, in consequence of the rapidity with which the charcoal burned away. At this period of the experiments several of the porous pots burst, and many of the copper slips became disconnected from the zinc cylinders, by the combustion of the solder; notwithstanding, however, this interruption of the circuit, the arc of light between the coke points was about an inch long, and the heat of the flame deflagrated a file." Voltaic arc produced by Callan's battery.

Ease of obtaining large currents from dynamos.

No one, at the present time, would think for a moment of taking the trouble to set up such a voltaic battery, since the mere throwing of a belt on the driving pulley of a suitable dynamo will instantly produce powerful currents.

During the early controversy between the advocates of the contact theory and the chemical theory of the voltaic cell, De Luc constructed a battery in which the separate couples consisted of silver and zinc, separated by disks of writing paper. De Luc believed that he, here, had a battery in which no liquid substance whatever was employed. For this reason his contrivance is frequently called the dry pile or battery. De Luc formed this pile as follows:

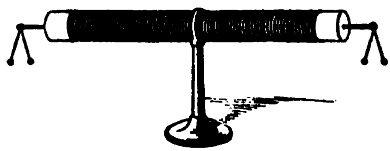


FIG. 139.—De Luc's Dry Pile, causing repulsion of pith balls.

De Luc's dry pile.

He coated one surface of a sheet of writing paper with a sheet of thin silver-foil, and then cut out circular disks about half an inch in diameter by the use of an ordinary punch. He employed sheets of paper covered in a similar manner, with a thin coating of zinc, from which he also cut circular disks. The separate disks were then placed inside a glass tube, carefully varnished, care being taken to observe the same order of arrangement throughout; viz., silver, zinc, paper, silver, zinc, paper, the top ending with a zinc and the bottom of the pile with a silver disk. The disks were then firmly pressed together inside a glass tube, and the tube capped with brass plates. Such a dry pile, consisting of some 1,200 separate disks, is shown in Fig. 139. When suitably sepa-

rated, the E.M.F.'s supplied are sufficiently powerful to cause pith balls to be repelled, as shown in the figure. By means of two such piles he rang a chime of electric bells by the alternate attractions and repulsions of a suitably supported clapper. By these piles De Luc kept electric bells ringing constantly for a period of some two years.

Zamboni's dry pile.

In 1812, Zamboni greatly improved De Luc's so-called dry pile, by covering a strip of paper on one side by a thin coating of black oxide of manganese, and on the other side by a thin sheet of tin-foil. Some very curious experiments were tried with dry piles so constructed.

Singer's dry pile of 20,000 couples.

In a dry pile constructed by Singer, in which some 20,000 couples of silver and zinc were employed, bright sparks were produced when a wire connected with one of the poles of the battery was drawn rapidly over the surface of a file connected with the other pole. A Leyden jar formed of very thin glass and containing some 50 square inches of surface, after being charged for ten minutes with this pile, produced a discharge sufficient to fuse a platinum wire one inch in length and $\frac{1}{5,000}$ of an inch in diameter. Gassiot, by means of 10,000 couples of Zamboni's pile, charged a Leyden-jar battery sufficiently to obtain disruptive discharges in air 1-16 of an inch in length.

De Luc's invention of the so-called dry pile was heralded by the advocates of the contact theory as a proof that electricity can be produced by the mere contact of dissimilar metals. It was argued that here were piles containing absolutely no fluid electrolyte whatever, and, moreover, alluding to the fact already referred to, that a pile constructed by De Luc

had kept a bell ringing for two years, it was claimed that such piles, when properly constructed, should keep them ringing forever—which would have been an exceedingly unscientific statement for any one to make had the doctrine of the conservation of energy then been known.

Erroneous belief as to absence of electrolyte in so-called dry pile.

In point of fact, the dry piles of the preceding type are only relatively dry. The paper employed attracts and absorbs sufficient moisture from the air to permit it to slowly act chemically on one of the elements of the pile.

FIG. 140.—A so-called Dry Pile.

Dry piles are now constructed in which a liquid electrolyte is purposely introduced, so as to ensure a proper amount of slow chemical action on one of the elements. A very common form of dry pile is shown in Fig. 140. Its advantage consists in the fact that the comparatively small quantity of liquid which such piles contain permits them to be readily carried about from place to place. The so-called dry piles either absorb the necessary liquid from the air, or take it from the disks of moistened cloth that are placed between the separate elements. Sometimes, liquids are introduced into the so-called dry cell in some absorbing medium like sawdust; or, the

liquid itself may be made into a jelly-like mass by admixture with suitable substances.

If a zinc-copper couple be immersed in a solution of zinc sulphate, the zinc plate being suspended near the top of the containing vessel, and the copper being placed at the bottom of the vessel, a current of electricity, if made to pass through the zinc sulphate between the two plates, from the copper plate to the zinc plate, will decompose the solution, and cause metallic zinc to be deposited on the surface of the zinc plate, and form a concentrated solution of copper sulphate, which will accumulate at the bottom of the jar around the copper plate. In this condition, the cell practically becomes a gravity-Daniell cell, and will yield electrical current until all the copper sulphate has been converted into zinc sulphate. In this condition, it can again be converted into a voltaic cell by sending a charging current between the two plates. Such a contrivance constitutes the early Thomson-Houston storage cell. In practice, such a cell would require a diaphragm to be placed below the zinc plate, in order to prevent metallic zinc from falling on the copper plate.

Thomson-Houston storage cells or accumulators.

Similarly, when two plates of metallic lead are immersed in a dilute solution of sulphuric acid and water, and a current of electricity is sent through the solution from plate to plate, a chemical decomposition occurs, and one of the plates becomes covered with a substance called the peroxide of lead, and the other with finely divided metallic lead. Peroxide of lead accumulates on the surface of the plate connected with the positive electrode of the charging electric source, and the metallic lead is deposited on the plate connected with the negative electrode of such source.

The lead plate storage cell or accumulator.

When the charging current ceases to pass, the cell becomes practically a voltaic cell, and will produce an electric current which will pass through such cell in a direction opposite to that in which the charging current passes, that is, in the charged cell the current will pass from the plate covered with spongy lead to the plate covered with lead peroxide. In other words, the plate covered with spongy lead forms what is called in the liquid the positive plate, and the plate covered with lead peroxide, the negative plate.

Polarity of the lead-lead peroxide storage cell.

Such cells constitute the so-called storage cells or accumulators. They are sometimes called secondary cells, in order to distinguish them from the ordinary voltaic cells, which are called primary cells. Storage cells or accumulators are properly electric sources. For their thorough understanding a knowledge of electro-chemistry is necessary. We will, therefore, leave their further description until we have fully stated the phenomena of electro-chemistry, which we will do in another volume of this book.

Primary and secondary cells.

CHAPTER XXV

THERMO-ELECTRICITY

"The quantity of force which can be brought into action in the whole of nature is unchangeable, and can neither be increased nor diminished."—HELMHOLTZ

ONE of the most important generalizations ever made in physical science, is what is commonly known as the doctrine of the conservation of energy. It is to the discovery of this doctrine that the Nineteenth Century owes a large part of its advance in physical science. It will be well, therefore, to briefly describe its principles, since they apply with equal force to electricity as to all other branches of physical science.

Doctrine of the conservation of energy.

The word energy means the capability of doing work. When any work is done some force must act through a distance; or, in other words, energy must be expended. But the expenditure of energy must not be confounded with its annihilation. Energy is never annihilated or wiped out of existence. It merely changes its form, disappearing in one particular form only to re-appear in some other form. For example, take the case of a pump filling a reservoir with water. The mechanical energy expended by a steam engine does work in raising water from a lower level to the level of the reservoir. The mechanical energy of the steam engine disappears only to re-appear when the stored water in the reservoir escapes. So long as the water remains in the reser-

Energy can neither be created nor annihilated

Transformation of electric energy.

voir it does no work; but let the water run out of the reservoir, and the energy re-appears, and may be expended in turning a water-wheel, which may transfer its energy to a dynamo electric machine, which, in turn, may convert electric energy into mechanical energy. So, too, the electric energy may be transformed or converted into heat or light energy. In all of these cases, however, no energy is lost. It has merely been changed or transformed. In other words, there has been neither increase nor decrease in the total quantity of the energy.

Why perpetual motion is impossible.

It might be supposed from the above doctrine that if the mechanical energy liberated by the water escaping from the reservoir were employed to drive a dynamo electric machine, and the electricity produced by this machine employed to drive a pump, then such pump should be able to return all the water back again into the reservoir, and that, therefore, such a system would be practically a case of perpetual motion. That this can not be done we all know. The reason is, that in practice losses invariably occur in the devices employed for transforming the energy, and that these losses, while by no means annihilating a part of the energy, nevertheless, so change a part of it into such a form as heat, etc., that it can not be immediately utilized in directly returning the water to the reservoir. This appearance of energy in a form in which it can not be immediately utilized by man, is sometimes called the degradation or dissipation of energy, because here some of the energy becomes non-available to man. For this reason energy is sometimes divided into available and non-available energy.

Degradation or dissipation of energy.

Now, concisely stated, the doctrine of the conservation of energy is as follows: There exists in the

universe a definite quantity or store of energy. This amount is fixed and unalterable, and can neither be increased nor decreased. The doctrine of conservation of energy is, therefore, sometimes called the doctrine of the indestructibility of energy. Since all natural phenomena are results produced by changes or transformations of energy, it followed that, as soon as scientific men were aware of the fact that when energy disappears in one form it must necessarily re-appear in another form, they were on the lookout for such re-appearance, and that, therefore, a rapid advance was made in physical science. It may be well, before leaving the doctrine of the conservation of energy, to annex the following quotation taken from Professor Tyndall's work on "Heat as a Mode of Motion." The high rank in which scientific men generally hold this important generalization, and the wonderful range of phenomena to which its principles extend, will be readily seen:

Concise statement of the doctrine of the conservation of energy.

"Still, presented rightly to the mind, the discoveries and generalizations of modern science constitute a poem more sublime than has ever yet been addressed to the imagination. The natural philosopher of to-day may dwell amid conceptions which beggar those of Milton. So great and grand are they, that in the contemplation of them a certain force of character is requisite to preserve us from bewilderment. Look at the integrated energies of our world—the stored power of our coal-fields; our winds and rivers; our fleets, armies, and guns. What are they? They are all generated by a portion of the sun's energy, which does not amount to $\frac{1}{2,300,000,000}$ of the whole. This is the entire fraction of the sun's force intercepted by the earth, and we convert but a small fraction of this fraction into mechanical energy. Multiplying all our powers by

Tyndall on the indestructibility of energy.

Enormous energy in the sun. Small amount reaching our earth.

millions of millions, we do not reach the sun's expenditure. And still, notwithstanding this enormous drain, in the lapse of human history we are unable to detect a diminution of his store. Measured by our largest terrestrial standards, such a reservoir of power is infinite; but it is our privilege to rise above these standards, and to regard the sun himself as a speck in infinite extension—a mere drop in the universal sea. We analyze the space in which he is immersed, and which is the vehicle of his power. We pass to other systems and other suns, each pouring forth energy like our own, but still without infringement of the law, which reveals immutability in the midst of change, which recognizes incessant transference or conversion, but neither final gain nor loss. This law generalizes the aphorism of Solomon, that there is nothing new under the sun, by teaching us to detect everywhere, under its infinite variety of appearances, the same primeval force. To Nature nothing can be added; from Nature nothing can be taken away; the sum of her energies is constant, and the utmost man can do in the pursuit of physical truth, or in the applications of physical knowledge, is to shift the constituents of the never-varying total. The law of conservation rigidly excludes both creation and annihilation. Waves may change to ripples, and ripples to waves; magnitude may be substituted for number, and number for magnitude; asteroids may aggregate to suns, suns may resolve themselves into flora and fauna, and flora and fauna melt in air—the flux of power is eternally the same—it rolls in music through the ages, and all terrestrial energy—the manifestations of life as well as the display of phenomena—are but the modulations of its rhythm."

Neither creation nor annihilation possible.

There are, in general, different ways in which

electric energy can be obtained by the transformation of some other form of energy: viz., by the transformation of mechanical into electric energy; by the transformation of chemical into electric energy; and by the transformation of heat or thermal into electric energy. Of these we have already studied, under the head of frictional electricity, one of the ways in which mechanical energy can be transformed into electric energy of high electro-motive force. We have also seen how, in the voltaic cell, chemical energy can be transformed into electric energy. Let us now inquire how heat or thermal energy can be transformed into electric energy.

Three general ways in which electric energy can be obtained

The discovery of the means by which heat energy can be transformed into electric energy was made by Professor Seebeck, of Berlin, in 1821. Seebeck thus enriched electric science by the invention of an entirely new electric source; viz., the thermo-electric cell.

Seebeck's discovery of thermo-electricity, in 1821.

Like all great discoveries, that of the thermo-electric cell was not accomplished by the work of a single man. Seebeck was preceded by hosts of other discoverers, who prepared the way for the great discovery of the means for obtaining, in a fairly practicable form, electric currents by the direct transformation of heat energy. But Seebeck first showed the means by which practical results could be obtained, and is correctly credited with the honor of the invention or discovery of the new electric source. We have already briefly alluded, under the head of pyro-electricity, to the production of electricity in bad conductors, such as certain crystalline bodies. The currents, however, thus produced were necessarily exceedingly small, on account of the electric resistance of the conducting substances

Seebeck preceded by discoveries of pyro-electricity.

Difference between pyro-electricity and thermo-electricity.

in which electricity was produced. Both pyro-electricity and thermo-electricity are produced by differences of temperature. The term pyro-electricity, however, is generally retained for the production of electricity in bad conductors by differences of temperature, while thermo-electricity is employed to signify the production of such currents in good electric conductors. Since the description we have already given of pyro-electricity was purposely very brief, it will be necessary here, at somewhat greater length, to describe some of the leading phenomena in this branch of electric science.

Origin of word tourmaline.

The effect of changes of temperature in crystalline bodies was noted at a very early date. Pliny, about 100 A.D., refers to the fact that when a certain crystalline stone is heated in the sun, it thereby acquires the property of attracting light bodies to it, just as it would had it been rubbed against the clothing. De la Rive states, that toward the end of the seventeenth century, some Dutch merchants brought from the island of Ceylon a stone which, when placed on hot ashes, attracts them, and then immediately afterward repels them. This stone was, therefore, called the "tournamal" of "ashes-attractor." This mineral is now called tourmaline, and received its name from the above-mentioned fact.

Some eminent students of pyro-electricity.

The pyro-electric properties of tourmaline and other mineral substances have been carefully studied by Æpinus, Bergman, Canton, Becquerel, Brewster, Riess, and Du Bois-Reymond. It was Riess who proposed the names analogous and antilagous poles for the pyro-electric poles of crystalline substances. The word analogous refers to the fact that, at this pole there is a similarity or analogy between the plus sign, which represents the character both of the

electricity and of the temperature, the analogous pole being the pole whose positive electricity increases as its temperature increases. The antilagous pole, on the other hand, is the pole at which the reverse effects are observed, that is, its electricity decreases while its temperature increases.

It has been shown that a great variety of crystalline substances, both natural and artificial, possess pyro-electric properties. Brewster names, among others, the following natural crystals as possessing such properties; viz., calc spar, beryl, heavy spar, fluor spar, diamond, amethyst, quartz, native sulphur and the garnet; and among artificial crystals, **Brewster on natural and artificial pyro-electric crystals.**

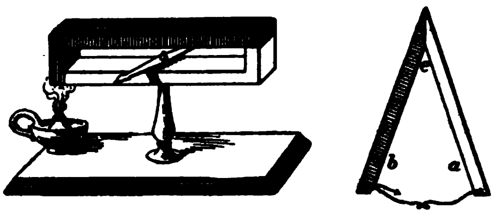


FIG. 141.—Seebeck's Apparatus for Producing Thermo-Electric Currents.

tartaric acid, chlorate of potash, green vitriol, sugar, sugar of lead, carbonate of potash and corrosive sublimate.

Coming now to the discovery by Seebeck, in 1824, of the production of electricity in good conductors, such as metallic bodies, by means of differences of temperature, we note the discovery that when any two different metals of unlike crystalline structure and conducting power are connected by means of solder, and the junction either heated or cooled, an electric current flows across the junction generally to the poorer conducting metal. For example, if, as in Fig. 141, at the right-hand side of the figure a bar **Seebeck's experiments in thermo-electricity.**

of bismuth *b*, and a bar of antimony *a*, be soldered together at the junction *e*, and the free ends be connected by means of electric wires, as shown, near the junction *e*, an electric current flows through the circuit from the bismuth through the conducting wires or circuit outside the metals to the antimony. In other words, the current flows from the junction through the poorer conducting metal, that is, the bismuth, to the outside circuit, and from this to the better conducting metal, that is, the antimony. The combination of two different metals forms what is called a thermo-electric pair or couple, in order to distinguish it from a voltaic pair or couple, which is sometimes also called a hydro pair or couple. As in the case of the voltaic cell, the different metals of a thermo-electric cell are called the thermo-electric elements.

Thermo-electric pair or couple.

If the elements of a thermo-electric couple be made in the shape of a hollow rectangle, such as shown at the right-hand side of Fig. 141, where the bismuth bar is represented by the shaded part of the rectangle, and the antimony bar by the unshaded part. and the bars be soldered together at their junctions, the thermo-electric current produced by heating one of the junctions, as by an alcohol lamp, will produce a current sufficiently strong to deflect a magnetic needle supported, as shown, on a vertical pivot. This deflection of the needle is due to the fact that a current of electricity, flowing through a conductor, always renders that conductor magnetic, as will be thoroughly explained in another part of this book.

Deflection of magnetic needle by thermo-electric current.

As in all electric sources, a thermo-electric couple produces electro-motive forces, or thermo-electro-motive force, and it is this electro-motive force that sets the electricity in motion. In any thermo-

Thermo-electro-motive forces.

electric couple, the difference of temperature between the opposite junctions determines the value of the electro-motive force produced. Therefore, the expedient is sometimes adopted of cooling one junction, while the other junction is being heated.

The value of the electro-motive force produced by any thermo-electric couple does not, however, only depend on the difference of temperature. It also depends on the character of the elements of the couple. Metallic substances can be arranged in a series, called a thermo-electric series. In such a series each metal is positive with reference to any metal further down in the series:

Thermo-electric series.

+Bismuth	.000089 volts
German Silver	.000018 volts
Lead	.000000 volts
Platinum	.000009 volts
Zinc	.0000037 volts
Copper	.0000038 volts
Iron	.0000175 volts
—Antimony	.0000226 volts

Small values of the thermo-electro-motive forces.

In the thermo-electric series given above, each metal is positive to the metal further down in the list. The thermo-electro-motive force is given in decimals of a volt, for the value of a thermo-electric couple formed by each of the metals mentioned with lead taken as the standard. For a difference of temperature of 1° C., or 1.8° F., the exceedingly small value of the thermo-electro-motive forces produced by thermo-electric couples will be readily seen, amounting as it does to but a few millionths of a single volt; in the case of the most powerful couple shown in the above table; viz., the bismuth-antimony couple, the value being but .000117 of a volt.

During his investigations, Seebeck discovered that it is possible to form thermo-electric couples from

two plates of the same metal, provided differences exist in their crystalline structure; *i.e.*, if one plate be crystalline and the other non-crystalline; or, as it is called in science, amorphous, or devoid of crystalline form. When a difference exists in their molecular structure, even two plates of the same metal may form a thermo-electric couple, as, for example, a plate of annealed steel, and a plate of hardened steel. Indeed, as Yelin has proved, thermo-electric currents can be produced in bars of metals that are homogeneous throughout their entire length, that is, which have, throughout their length, the same crystalline or non-crystalline structure; for example, a

Thermo-electric couples possible from pairs of the same metals if crystalline structure or molecular grouping differs.

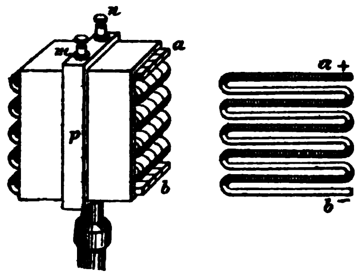


Fig. 142.—Nobili's and Melloni's Thermo-Electric Pile or Battery.

bar of bismuth has a thermo-electric current developed by simply heating one part of the bar higher than another part.

In order to increase the feeble E.M.F.'s produced by thermo couples, a number of such couples are connected together in series, so as to form what is called a thermo-electric battery. Here, as in voltaic batteries, the separate E.M.F.'s of all the thermo couples are added. This has been done by Nobili and Melloni to form the thermo-electric pile or battery shown in Fig. 142. This pile consists of some fifty pairs of bismuth and antimony placed side by

Thermo-electric batteries or piles.

side, soldered at their extremities, and insulated from one another by some insulating substance, as shown on the left-hand side of the figure. These separate piles are then placed vertically over one another, as shown at the right of the figure, care being taken to connect all the separate thermo couples in series, so as to add their thermo-electro-motive forces. The poles or electrodes of the thermo battery thus formed are connected to two brass binding screws, placed on top of the battery. By the arrangement here adopted it will be seen that the alternate junctions of all the pairs in the pile come on opposite ends of the pile, all the even junctions coming at one end, and the odd junctions at the other end. This permits all the junctions on one face to be heated, while all those on the opposite face are cooled, and thus is obtained the sum of the electromotive forces produced in all the separate couples. This form of thermo-electric pile is sometimes called Melloni's thermo-multiplier.

Arrangement of odd and even junctions in thermo-piles.

Melloni's thermo-multiplier.

Melloni employed this form of electric pile in his study of radiant heat, that is, the heat that is given off from the surface of heated bodies. A thermo-multiplier, when employed in connection with an electrical instrument known as a galvanometer, affords a very sensitive means for the detection of small differences of temperature. A galvanometer consists of a device for measuring the strength of an electrical current by the deflection or deviation it produces in a magnetic needle. The galvanometer is an instrument that we can only thoroughly explain after we have studied the magnetic effects produced by the electric currents. It will suffice now to state that it consists practically of the same device as already shown in connection with Fig. 141, only, instead of a single hollow rectangular frame of metals,

Melloni's thermo-galvanometer.

the galvanometer proper consists of a number of turns of insulated wire, each of which when traversed by an electric current becomes a magnet. The effect of such a coil on the magnetic needle is, therefore, greater than would be the effect of a single coil, like the hollow rectangular conducting path formed of bismuth and antimony employed by Seebeck in his original experiment. In Seebeck's experiment the needle was deflected by a magnetic effect produced in a single turn or circuit, while, in the galvanometer, the needle is deflected by a number of such turns.

Principle of the galvanometer.

Melloni's thermo-multiplier is shown in connection with the galvanometer in Fig. 143. Here insulated

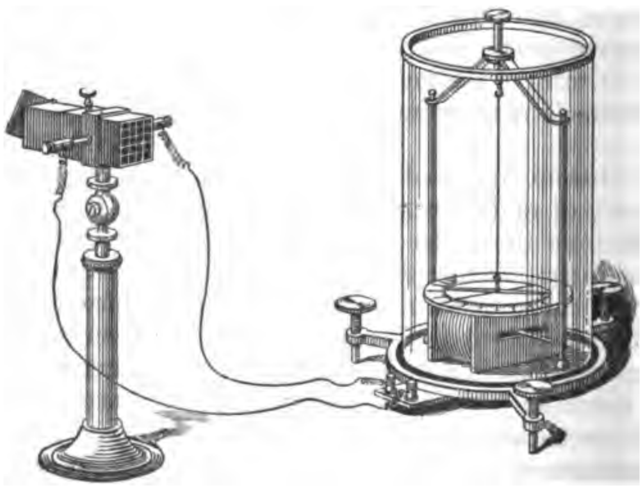


Fig. 143.—Melloni's Thermo-Galvanometer.

metallic wires, connected with the poles of the thermo-multiplier, carry the current to the terminals of the galvanometer, shown on the right-hand side of the figure. The galvanometer needle is suspended

by a silk fibre inside a hollow coil, consisting of many turns of insulated wire. In employing the thermo-pile for such experiments, the faces of the pile are blackened with a coating of lampblack, so as to readily absorb any radiant heat that falls on them. When only one side of the pile is to be exposed to the radiant heat, the other face is kept at a constant temperature by being covered with a metallic plate, which comes near to, but does not touch the face of the pile. This combination of thermo-pile and galvanometer can be made so sensitive to radiant heat that the galvanometer needle is deflected by the heat coming from the body of a person at a distance of twenty-five or thirty feet from it. Where small differences of temperature existing between two separate and distinct sources of heat are to be measured, one face of the pile is exposed to the radiant heat from one source, and the other face of the pile to the radiant heat from the other source. If the two sources are at the same temperature the opposite currents produced neutralize each other, but if the other source differs but slightly in temperature, the needle of the galvanometer will be deflected in a direction which will readily enable one to ascertain which is the higher temperature. Moreover, the amount of the deflection will enable the difference of temperature to be calculated. This combination of apparatus is sometimes called a thermo-galvanometer.

Sensibility of Melloni's thermo-galvanometer.

In a lecture on the thermo-electric pile and galvanometer, in Tyndall's "Heat as a Mode of Motion," before referred to, the author thus describes the action of this apparatus, as well as its method of use:

Tyndall on the thermo-pile and galvanometer.

"At the present moment the needle is quite at rest, and points to the zero mark on the graduated disk underneath it. This shows that there is no current

passing. I now breathe for an instant against the naked face, A, of the pile—a single puff of breath is sufficient for my purpose—observe the effect. The needle starts off and passes through an arc of 90°. It would go further, did I not limit its swing by fixing, edgewise, a thin plate of mica at 90°. Take notice of the direction of the deflection; the red end of the needle moved from me toward you, as if it disliked me, and had been inspired by a sudden affection for you. This action of the needle is produced by the small amount of warmth communicated by my breath to the face of the pile, and no ordinary thermometer could give so large and prompt an indication. We will let the heat thus communicated waste itself; it will do so in a very short time, and you notice, as the pile cools, that the needle returns to its first position. Observe, now, the effect of *cold* on the face of the pile. I have here some ice. but I do not wish to wet my instrument by touching it with ice. Instead of doing so, I will cool this plate of metal by placing it on the ice; then wipe the chilled metal, and touch with it the face of the pile. You see the effect; a moment's contact suffices to produce a prompt and energetic deflection of the needle. But mark the direction of the deflection. When the pile was warmed, the red end of the needle moved from me towards you; now its likings are reversed, and the red end moves from you toward me. Thus you see that cold and heat cause the needle to move in opposite directions. The important point here established is, that from the direction in which the needle moves, we can, with certainty, infer whether cold or heat has been communicated to the pile; and the energy with which the needle moves—the promptness with which it is driven aside from its position of rest—gives us some idea of the comparative quantity of heat or cold imparted to it in

Effect of cold on face of thermo-pile.

Heat and cold applied to pile produce oppositely directed currents.

different cases. In a future lecture I shall explain how we may express the relative quantities of heat with numerical accuracy; but for the present a general knowledge of the action of our instruments will be sufficient."

In 1887, Professor Boys greatly increased the sensitiveness of Melloni's apparatus by combining both a thermo couple and the galvanometer in the same instrument. He did this by forming a square metallic circuit, three of the sides of which consisted of fine copper wire, and the fourth side of a compound bar of antimony and bismuth, the separate bars of which were soldered side by side. He then supported this circuit on a thin rod, carrying a small mirror, and suspended the entire system by a torsion fibre, in a strong magnetic field. When radiant heat was allowed to fall on the antimony-bismuth junction, an electric current was produced, which, flowing through the suspended metallic circuit, was at once deflected by the magnetic field surrounding it. When suitably constructed, this instrument is so sensitive that it can detect radiant heat from a candle flame at a distance of more than a thousand feet, and can be made so delicate that it is possible to measure differences of temperature as small as the $\frac{1}{1,000,000,000}$ of a degree. Boys called this instrument the radio-micrometer. **Boys' radio-micrometer** **Sensitiveness of the radio-micrometer**

In 1881, Langley constructed an extremely sensitive form of instrument, which he called the bolometer. This instrument, although operated on a different principle, may properly be referred to here, since it is electrical in its action. **Langley's bolometer.**

The bolometer depends for its operation on the fact that the electric resistance of metals changes

with small changes in temperature. Langley placed two strips of platinum in such positions, as regards an instrument called an electric bridge or balance, that so long as both strips were equally heated the equilibrium of the balance was not disturbed; and, therefore, a delicate galvanometer placed in the circuit of the bolometer and balance would not be affected. If, however, while one of these strips was protected from the radiant heat of the source whose temperature was to be measured, the other strip was exposed to such radiation, then the temperature produced a change in the electric resistance of the exposed strip, which disturbed the electric balance, and so permitted the needle of the galvanometer to be deflected. In this manner, Langley was able to detect differences of the millionth of a degree Centigrade, and to accurately measure the one-thousandth of a degree C.

Construction and mode of operation of Langley's bolometer.

Delicacy of Langley's bolometer.

Langley thus describes his bolometer in Prof. C. A. Young's book on "The Sun":

"As the heat in the diffraction spectrum [a band of rainbow colors obtained from light reflected from a metallic surface roughened by numerous parallel lines drawn very near one another] is, at best, about one-tenth that in the prismatic spectrum [*i.e.*, the spectrum obtained by passing light through a prism], which is itself all but immeasurably small when distributed in approximately homogeneous rays—special apparatus has been devised for the peculiarly delicate measurements in the diffraction spectrum, which I have lately succeeded in making. The apparatus depends on the principle (not in itself at all new) that, if, of two wires from a battery, making the arms of an electric 'bridge,' or 'balance,' we warm only one, a galvanometer needle may be made to move, owing to the diminished current caused by

Langley's description of his bolometer.

Principle of bolometer.

the heat. But, though the principle is simple, the special application has been difficult. The instrument, as finally constructed for measuring most minute portions of radiant energy, as heat, uses strips of metal about $\frac{1}{10,000}$ inch thick as the balance-arms, and I have called it the Bolometer. With the one I am now using, a change of temperature of about 0.00001° Cent. in the strips is detected, a change of $\frac{1}{10,000}$ degree being noted instantly. As these strips are extremely minute, this implies a power of recognizing amounts of radiant heat smaller than those for which the thermo-pile is commonly employed. *How* small it is difficult to apprehend clearly, but it may be stated, in illustration both of the feebleness of radiant energy in some parts of the diffraction spectrum and of the delicacy of the instrument, that the heat in certain ultraviolet rays can be detected by it in rather less than ten seconds, though the same radiation is so weak that, falling uninterruptedly for over one thousand years on a kilogramme of ice at 0° Cent. it would not wholly melt it."

Extremely feeble thermal action of violet rays of light.

Various attempts have been made to obtain from thermo-piles sufficiently powerful currents for ordinary electric work. Professor Dove made a form of thermo battery or pile, in which a hundred pairs of iron-platinum couples were soldered together in alternate lengths, and so wound on the surface of a wooden cylinder that all the iron-platinum junctions come on one side of the cylinder, and all the platinum-iron junctions on the other side; or, in other words, so that all the even junctions come on one side and all the odd junctions on the other. A current was produced by dipping one set of junctions in heated oil, while the other set was cooled.

Dove's thermo-pile or battery.

A form of thermo-pile capable of producing fairly large currents, is shown in Fig. 144. This pile was devised by Watkins, and consisted of a number of antimony-bismuth couples, alternately soldered together, so as to form the battery shown in the figure. The arrangement was such that one set of junctions came at the bottom of the pile, and the other set at the top. The differences of temperature were obtained by exposing one face of the pile to the radiant heat from a red-hot iron plate, and the other face to a lump of ice. This pile generated a current suffi-

Watkin's thermo-pile or battery.

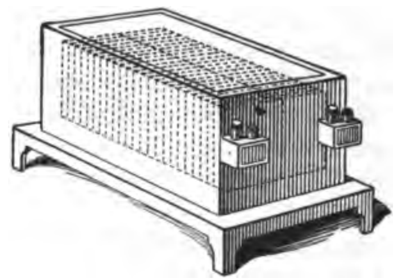


FIG. 144.—Watkin's Thermo-Electric Pile or Battery. The terminals or electrodes are shown provided with binding posts.

cient to produce disruptive sparks, heat wires, and cause chemical decomposition.

Clamond's thermo-pile

One of the most efficient forms of thermo-piles was that devised by Clamond and Mure. The thermo couples consisted of an alloy composed of zinc and antimony and a sheet of iron, respectively. In the pile of this description, shown in Fig. 145, there are ten elements, arranged as shown at the upper part of the figure. Each element is represented by F, and each alloy of zinc and antimony by A. The alloy elements, suitably separated, are placed, as shown, in the form of a circle. The iron strips

are fastened at one end on the inside of the alloy elements, and the other end on their outer edges. In

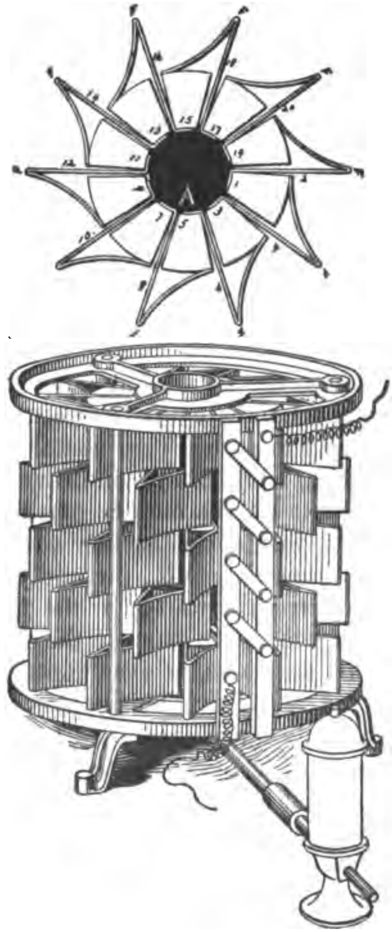


FIG. 145.—Clamond's Thermo-Pile or Battery. Note that in the ring-shape battery, shown at the upper part of the figure, that all the odd junctions, from 1 to 19, come on the side of the hollow space, and all the even junctions, from 2 to 20, come on the outside.

this manner the iron elements are caused to project sufficiently on the outside to present a large sur-

Detailed construction of Clamond's thermo-pile or battery.

face for cooling. An examination of the figure at the upper part of the drawing will show that all the separate elements are connected in series, and that the poles or electrodes of the ring-shaped battery, so formed, are situated at the unconnected alloy terminals. The battery itself is built up of a number of these ring-shaped elements, which are piled one upon the other, as shown at the lower part of the figure. The clamp connectors, shown at the right-hand side of this figure, are provided for coupling the separate ring-shaped batteries either all in series, or in multiple-series, as in the case of voltaic cells.

Electric data of Clamond's pile.

Thus arranged, the set of junctions to be heated all come inside a hollow cylindrical space, in which was placed an earthenware tube containing a number of small holes, while the junctions which were to be cooled all came on the outside of the pile. Gas jets are burned inside the earthenware tube, and heat one set of junctions; viz., the odd junctions, or those numbered from 1 to 19, in the ring-like element shown at the upper part of the figure, while the other set of junctions, or even junctions, from 2 to 20, are cooled by the air. This battery was capable of producing fairly large currents. In an improved form, consisting of 30 pairs of 100 elements, a current was generated capable of maintaining a voltaic arc, similar to that produced in an ordinary arc electric lamp. The electro-motive force of the pile was 109 volts, and its resistance 15½ ohms.

Gulcher's thermo-pile or battery.

An excellent form of thermo-pile, known as Gülcher's thermo-pile, is shown in Fig. 146. It consists of two series of thermo couples heated by a number of small Bunsen burners. The gas is supplied through a pipe, F. A battery of this descrip-

tion, containing sixty-six elements, will produce an E.M.F. of four volts, and, under favorable conditions, will sustain a current of three ampères, by a consumption of gas of about 6.4 cubic feet per hour.

The thermo-pile is certainly much better adapted to produce electrical currents than are ordinary voltaic cells, since all that is required is to turn on and ignite a gas jet or start a fire. Instead of burning zinc in costly acids, we burn gas or coal in air. Notwithstanding this convenience, the thermo-piles are but little employed, since, at present, the current they

Difficulties inherent in thermo-electric generators or thermo-piles or batteries.

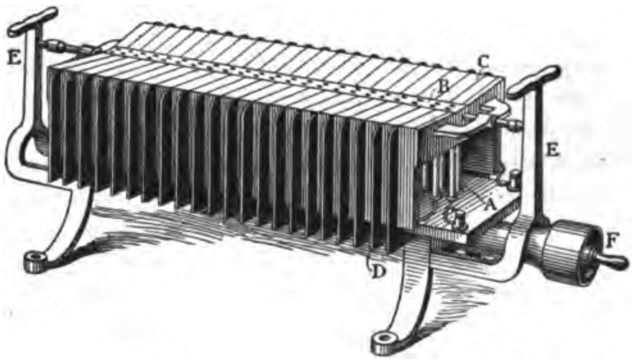


FIG. 146.—Gulcher's Thermo-Electric Pile or Battery. D shows a number of sheet-metal radiators provided for cooling the outside junctions.

produce is too small to be of much use. Moreover, their economy of conversion or transformation of energy into electric energy is low, much of the heat being lost. Then again a difficulty exists in obtaining the low resistance that such a generator should possess, in order to produce a large current. To produce a low resistance means to build the generator of good electrical conductors; but, unfortunately, good conductors of electricity are also good conductors of heat, and, if such be employed in thermo cells, it is difficult to keep one side of the junctions at a

Short useful life of thermo-piles.

high temperature, and the other side at a low temperature. Then again, a serious difficulty arises from the fact that a thermo-pile has a short useful life. It rapidly deteriorates, becoming practically useless in a few years. This is, probably, due both to the continued expansions and contractions of the cell, but especially to a change in the physical character of the metals at the junctions. However, it is possible that great improvements may still be made in thermo-electric generators or piles.

The Peltier effect.

In 1834, Peltier discovered that the passage of an electric current across the junction of a thermocouple, in a certain direction, develops heat, while its passage, in the opposite direction, across such junction absorbs heat. In other words, an electric current flowing in a certain direction across a thermo junction will heat it, but flowing in the opposite direction across such junction will cool it. In order to demonstrate this curious fact, Peltier replaced the fine platinum wire employed in a modified form of Kinnersley's electric thermometer by two small cylinders of bismuth and antimony soldered together end to end, so placed as regards the ball, that the junction came in the centre of the bulb. On sending an electric current across this junction from the antimony to the bismuth an increase of temperature was produced. On sending it in the opposite direction from the bismuth to the antimony a reduction of temperature was produced. In order to avoid the effect produced in the metals by the liberation of heat due to the passage of the electric current through the mass of the metal, Lenz modified this experiment by forming a circular aperture or hole at a part of the junction of a bismuth-antimony couple, and inserted the bulb of a small thermometer in the opening. When the current of a voltaic cell, consisting

Electric thermometer employed to demonstrate Peltier effect.

Lenz's experiment on the Peltier effect.

of a zinc-platinum couple, with about 155 square inches of surface, was passed from the bismuth to the antimony, the temperature fell 7.2° F. In this connection, Lenz performed the following extremely interesting experiment. By filling the circular hole, at the soldered junction of the bismuth-antimony couple above-described, with water, and covering all the apparatus, excepting at the soldered point, with melting snow, he obtained a temperature in all parts of the apparatus, including the water itself, of 32° F. Then, on the passage of the current in the proper direction, he succeeded in freezing the water and lowering the temperature of the ice so formed to 24° F.

Water frozen by the Peltier effect.

The change of temperature by the passage of an electric current across a thermo-electric junction, is called the Peltier effect. This effect includes both the case of heat developed at the junction when the current is crossing it in a certain direction, and heat absorbed, or cold produced at such junction, when the current is passing in the opposite direction. The Peltier effect thus differs from what is called the Joule effect, which refers to the heat produced in an electric conductor on the passage of the current, arising from the resistance which the conductor offers to such passage; viz., the Peltier effect is reversible; *i.e.,* the current heating the junction when passing in one direction, and cooling it when passing in the opposite direction; in the Joule effect it is not reversible, the same amount of heat being developed in a conductor no matter in what direction the current passes through it. Moreover, in the Peltier effect the heat evolved is proportional to the amount of current passing, so that if the current be doubled, the heat produced by the Peltier effect will be doubled; while in the Joule effect, the heat is pro-

Differences between the Peltier and the Jouleeffects

Differences in the amount of heat produced by the Peltier and the Jouleeffects

portional to the square of the current, so that if the current be doubled the amount of heat produced by the Joule effect will be increased fourfold.

Dr. Oliver Lodge thus speaks of reversible and irreversible heat, in his "Modern Views of Electricity":

Lodge on reversible and irreversible heat.

"In a simple, homogeneous piece of metal the heat produced by a current is utterly independent of direction: it is called irreversible heat; it is proportional to the square of the current strength, as Joule showed. But at a junction of different substances, or even at a junction of the same substance in two different states—two different temperatures, for example,—in addition to the irreversible heat produced by mere resistance there is reversible heat production, one which changes sign with the direction of the current, so that the current one way actually tends to cool the junction instead of heating it. With care this may be got to overpower and mask the irreversible heat, and a junction may be cooled and water frozen by steadily passing a moderate current in the right direction across it. This curious effect was discovered by Peltier.

Thermo-electric contact force.

"It may be considered as the fundamental fact of thermo-electricity. Its meaning is that something in the metals at the junction is helping to propel the current along; doing work in fact, and consuming its own heat in the process. The vibratory motion of the molecules is getting used up in propelling electricity. The contact force is acting in the direction of the current.

"If the current be reversed, it will be driven against the force of the molecules, and an extra amount of heat will be added to the irreversible or frictional generation of heat.

"This thermal evidence of contact force, though

the most direct, was not the earliest discovered. The earliest known fact in thermo-electricity was that in a complete circuit of different metals a current could be excited by having the parts at different temperatures; manifestly because these contact forces we have been speaking of change with temperature—some increasing, others decreasing. They are accurately balanced in a circuit of uniform temperature, but they have a resultant whenever the temperature is not uniform, and this resultant propels the current discovered by Seebeck."

Thermal evidence of contact force.

The Peltier effect may be shown experimentally as follows: A bar of bismuth B, and a bar of anti-

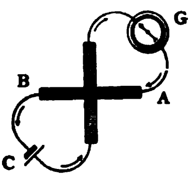


FIG. 147.—Peltier's Cross, for experimentally demonstrating both the Peltier changes of temperature by the passage of an electric current across ther mo electric junctions and the Seebeck effect of producing thermo-electric currents by such changes of temperature.

mony A, are placed at right angles to each other in the form of a cross, soldered together at their junctions as shown in Fig. 147. One set of the free ends is connected by means of conducting wires to a galvanometer G, and the opposite set similarly connected by means of conducting wires to a single voltaic cell C. This cell is so connected that it sends a current through the circuit across the thermo junction in such a direction as to develop heat. This heat in its turn will cause a thermo-electric current to be set up, which will pass in the direction indicated by the arrows, and will deflect the needle of the galvanometer in a certain direction. But, if

Experiment with Peltier's Cross.

the direction of the current in the cell be reversed, cold will be produced by its passage across the thermo-electric junction, and the thermo-electric current produced by such cold will now flow through the circuit connected with the galvanometer, in the opposite direction, as will be indicated by the movement of the galvanometer needle in the opposite direction to its former movement.

Thomson effect.

If a rod of iron or zinc be unequally heated, a current of thermo-electricity will thereby be generated, which will flow from the hotter to the colder parts of the circuit. In the case of an unequally heated bar of copper the direction of such thermo-electric currents is reversed. The effects thus produced in unequally heated metallic circuits are called Thomson effects. It follows, as a result of the Thomson effect, that when an electric current is sent through a copper conductor from the part that is heated to the part that is cooled, it meets with an electro-motive force that opposes its passage, and, therefore, develops heat energy; and that when it passes in the opposite direction, that is, from the cold to the hot part of the copper conductor, it absorbs heat.

IV

SOME OTHER ELECTRIC SOURCES

CHAPTER XXVI

HEAT CELLS. LIGHT CELLS

"These various attempts to solve the fascinating problem of the direct production of electrical energy from carbon are very interesting from the scientific standpoint; but the results are discouraging, and the difficulties to be overcome appear to be so numerous that there does not seem to be any very great hope that commercial success will be achieved, at least at present."—*Primary Batteries:* W. R. Cooper

Primary cells vs. steam-driven dynamo electric machines.

WE have already referred to the fact that no primary voltaic cell can compete with the dynamo electric machine in the economical production of electric current, since, in the voltaic cell we burn zinc in a costly acid, while in the case of the steam engine which drives the dynamo we burn coal in air.

The voltaic cell a far more efficient device than the steam engine.

The steam engine, however, is an exceedingly inefficient device for producing energy from the burning of coal in air. W. R. Cooper estimates that, under ordinary circumstances, in the case of a good modern steam-driven generating plant, running all day, such as is employed in electric lighting stations for driving the dynamos, the efficiency is not apt to be more than 6 per cent, that is, 94 per cent of the energy of the coal is lost or expended elsewhere, and only 6 per cent appears in the shape of electric energy; for, in a steam-driven dynamo plant, there are several conversions before the heat energy is

converted into chemical energy, while in the voltaic cell there is but one. It would seem, therefore, that it should be possible to ensure a far higher efficiency of the voltaic cell. W. R. Cooper discusses this question at length in his book on "Primary Batteries." He considers the case of a voltaic battery such as would be required at a central station for operating lighting apparatus, assuming it to consist of 100 cells capable of producing a difference of electric pressure of 100 volts, and of supplying 1,000 ampères. He finds, after making proper allowances for the different sources of loss, that, nevertheless, it is possible for such a battery to have an efficiency as high as 73½ per cent. At first sight, therefore, it would appear that such a voltaic battery should readily be able to compete with the steam-driven dynamo in the cost of electric current produced. Unfortunately, however, the cost for a given amount of electricity delivered, does not depend only on the efficiency, but also on the cost of the materials employed, on the cost of manufacture, and the handling of the apparatus, and on the interest on the money expended for the apparatus, so that, even with a much higher efficiency of the voltaic cell, the cost of producing by its means a certain quantity of electricity is very much higher than the cost of producing the same quantity by the ordinary steam-driven dynamo.

Cooper on the relative efficiencies of equal quantities of electricity by voltaic battery and a steam-driven dynamo plant.

It is a necessary condition that the material which is consumed in the electrolyte of a voltaic cell; *i.e.*, the zinc, or the material corresponding to the zinc, that is, the material which is electro-positive in the liquid, should be cheap. Moreover, it should be as highly electro-positive as possible, and should be capable of being used in connection with an electro-negative element, which is as highly electro-negative

Conditions for cheap voltaic cell.

as possible, so that the E.M.F.'s of the cell should be large. While the cost of such negative material is of importance, nevertheless, if such material can be employed without becoming commercially useless, its cost is not a matter of such great importance.

Carbon-consuming cells.

Attempts have, therefore, been made to produce practical cells in which coal, burning in air, shall replace zinc, burning in acid. Coal is cheap, and the energy a given quantity of coal liberates is comparatively great. It is, therefore, easy to see why attempts have recently been made to produce voltaic cells of an entirely new type, in which the energy liberated by the burning coal can be directly converted into electric energy. If such attempts prove successful the efficiency of cells so constructed would be far greater than that of the steam engine, provided always that the cost of construction, maintenance of the cell, and interest charges on the same, do not prevent its high efficiency from producing cheap currents. If, for example, such cells could be made to produce currents whose relative cost as compared with that of dynamos was as 73½ is to 12, then we would have such batteries producing electricity about six times cheaper than it is possible by the best steam-driven dynamos of to-day; and, under such circumstances, it is clear that the steam engine, so far as its ability to produce electric current is concerned, must become a thing of the past, since it would then be entirely replaced by the new battery.

Possible efficiency of carbon-consuming cells.

Cells of the type we have above referred to may be called carbon-consuming cells. They must not be confused with cells of the Bunsen or Grove type. In carbon-consuming cells the carbon is the positive element in the electrolyte, since in such cells the carbon is oxidized or consumed, while in the Bunsen and

Grove cells the carbon is the negative element in the electrolyte.

Becquerel carbon-consuming cell.

So-called pyro-electric couple.

Both Becquerel and Jablochkoff have attempted to produce carbon cells in which rods of carbon are dipped in baths of fused caustic potash. In the Becquerel cell fused nitre was placed in platinum vessels, and a single carbon rod was brought to incandescence by being dipped in the fused mass. This combination produced an electro-motive force of about half a volt. Another Becquerel cell of a somewhat similar form, and which may be called a pyro-electric couple, consisted of a bar of cop-

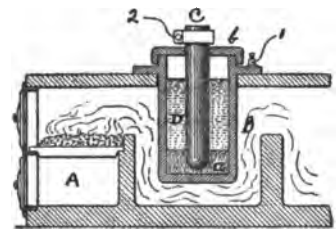


FIG. 148.—Edison Carbon-Consuming Heat Cell.

per and a bar of iron dipped in a mixture of fused glass and carbonate of soda.

Jablochkoff carbon cell.

In the Jablochkoff cell the fused nitrate of potash or soda was placed in an iron vessel. A rod of carbon was immersed in the fused nitrate. The electrodes of the cell consisted respectively of the conductors connected with the iron vessel and the carbon rod.

Edison carbon cell.

In the Edison carbon cell, shown in Fig. 148, the heat of the furnace, A, acting on the iron pot, B, decomposes certain oxides, salts, or other chemical compounds, with which it is filled. In this manner

a soluble electrode, C, formed of carbonaceous materials, is acted on at high temperatures. The soluble electrode rests on a block of fire clay at *a*, and is surrounded by the fused mass in B. A cover, *b*, also of fire clay, is provided to prevent the loss of heat and gases from D. The terminals or electrodes of the cell are shown at 1 and 2, connected respectively to the iron body and to the soluble electrode. It is claimed that the products of the reduced oxides may be re-oxidized and used over again.

Reed heat cell. C. J. Reed has shown that if two pieces of Bessemer steel, cut from the same bar, so as to ensure the same molecular structure and chemical composition,

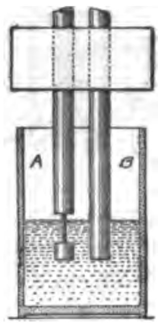


FIG. 149.—The Reed Heat Cell.

are immersed in a fused mass of caustic soda, they will show differences of electric potential, provided they are unequally heated. Reed assured this unequal heating by cutting a deep groove, such as is shown at A, in Fig. 149, which is taken from Volume XV. of the "Transactions of the American Institute of Electrical Engineers." The other rod was of equal diameter throughout. When these rods were immersed in fused alkali contained in a vessel of cast-steel, A will acquire a temperature much

higher than that of B, owing to the fact that, in B, the heat is conducted away more rapidly than in A. With the differences of temperature so obtained an electro-motive force was produced of something in the neighborhood of one volt, under the most favorable conditions. Generally, however, the values are far smaller. Reed found that rods of other materials, such as carbon, copper, and various other metals, could be substituted for steel rods.

Jacques heat cell.

A form of carbon cell, called the Jacques cell, is shown in Fig. 150. This appears to be a great

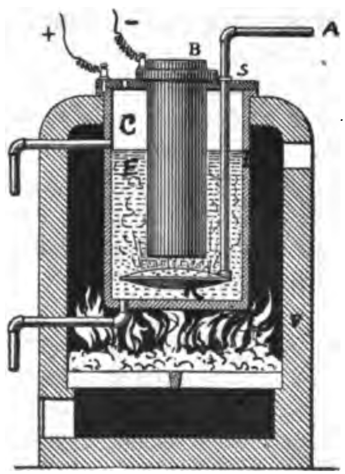


FIG. 150.—The Jacques Heat Cell.

improvement over pre-existing cells. It consists of carbon combined with iron. The fused caustic soda is contained in an iron vessel, I, which acts as one of the plates of the cell. The carbon, C, is immersed in the fused soda. A pump is provided for the purpose of driving a stream of air through the fused soda. This blast of air is distributed by means of the device shown at R. The cell is placed inside a

furnace, F, by means of which a temperature of about 932° F. is maintained. The stream of air passing through the fused caustic soda in E oxidizes the carbon and forms carbonic acid gas, most of which bubbles through the fused solution and escapes, it is claimed, without action on the fused soda. This cell produces an E.M.F. of about one volt, and is capable of sustaining a fairly strong electric current. Considerable doubt, however, exists as to how the E.M.F. is produced, some asserting that the E.M.F. is really a thermo-electric E.M.F., the iron forming a heated junction, and the carbon, cooled by the air, forming the cold junction. On the other hand, it is claimed by others that the E.M.F. is the result of a true chemical action on the carbon element. The Jacques cell, unfortunately, develops considerable local action. The expensive electrolyte of this cell, however, as has been pointed out by Prof. Elihu Thomson, has a short life, owing to the fact that, despite assertions to the contrary, the carbonic acid liberated does act sensibly on the fused soda.

Elihu Thomson on the Jacques heat cell.

A cell closely resembling the Jacques cell is called the Blumenberg cell. This cell is shown in Fig. 151. Here the carbon element, C, is immersed in a fused mixture of lime, caustic soda and cryolite, contained in an iron or copper vessel, D, which forms the other plate of the cell. A stream of superheated steam, produced by the heat of the furnace acting on the water in the boiler, B, forced through the fused electrolyte, replaces the air in the Jacques cell, and, as in that cell, acts on the carbon.

Blumenberg heat cell.

The important problem of producing electricity directly by the combustion of carbon has not, as yet, been solved. The difficulties in the way of this so-

lution appear to be great. If, however, this problem should ever be solved, it would be difficult to estimate the value that would thus be given to the world. Consequently, scientific men appear unwilling to abandon efforts to solve it. Let us hope, discouraging as is the outlook to-day, that in the near future some more practical solution will be proposed than has been heretofore.

Electricity produced cheaply from direct burning of coal possible.

Conversion of light energy into electric energy.

We have seen that mechanical, chemical, and thermal energy can be converted into electric energy.

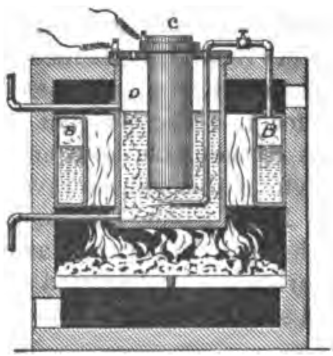


FIG. 151.—Blumenberg Heat Cell. Note the means provided for the escape of superheated steam, etc.

We will now show that the energy of light is also capable of being converted into electric energy.

Becquerel's early form of light cell.

As early as 1840, Becquerel constructed a cell formed of platinum plates, immersed in an alkaline solution. This cell consisted of a dark box, blackened on the inside, so as to prevent the reflection of light, and divided into two compartments by means of a thin membraneous partition. When sunlight was allowed to fall on one of the platinum plates the illumined plate thereby became negatively electrified as compared with the liquid. When the alka-

line solution was replaced by an acid solution, the illumined plate became positively electrified as compared with the liquid. That these effects were not caused by the heat accompanying the light, was shown by the fact that no action could be observed when the plate was illumined by any colored light in the spectrum except violet, blue and indigo rays. The best results were obtained by the action of violet light. This is interesting when taken in connection with what we have already said concerning the effects of violet light, either as to the influence this light has in starting disruptive electric discharges, or as to the effects alleged to have been produced by it in magnetizing a steel needle. Becquerel also showed, when the metallic plates in the cell above referred to were covered with such photographic chemical substances as silver chloride or bromide, that at the moment these substances are decomposed by the action of light, well-marked electric currents are produced.

Effects of violet light on light cells.

In 1873, Willoughby Smith called attention to the discovery of J. A. Mayhew, of the power that light possesses of greatly changing the electric resistance of a non-metallic element named selenium. This element is somewhat allied to sulphur, and was discovered by the chemist Berzelius, in a red deposit found at the bottom of the lead chambers employed in the manufacture of sulphuric acid. Similar properties are possessed by telurium, though in a smaller degree.

Effect of light on electric resistance of selenium.

Selenium occurs in two different forms; viz., in the vitreous form, and in the form of an amorphous red powder. Fused vitreous selenium possesses an extremely high electrical resistance, a rod of a given area of cross-section and length having some

High electric resistance of selenium.

38,000,000,000 times the resistance of a copper rod of equal length and area of cross-section.

The curious property possessed by selenium of having its electric resistance lowered by light has caused numerous investigations to be made with the idea of ascertaining, if possible, the reason for such changes. We will briefly refer to a few of these investigations. In 1877, Messrs. Adams & Day published in the "Philosophical Transactions" for that year, the results of numerous experiments they had made in this direction. As a result of these investigations they reached the conclusion that the electric conductivity of selenium differed from the electric conductivity of metallic conductors, partaking of that kind of conduction which occurs when electric currents pass through conducting liquids called electrolytes, in which the liquid is decomposed by the passage of the current. In other words, that this conduction was electrolytic conduction, and not metallic conduction.

Electric conductivity of selenium a species of electrolytic conduction

In 1885, C. E. Fritts, of New York, conducted a series of investigations, which resulted in the production of selenium cells much more effective and more sensitive to light than those heretofore produced. In the Fritts cell, the selenium was formed in very thin plates, under circumstances that caused the opposite faces of the plates to become polarized, or to exist in different electrical conditions. This was accomplished by pouring melted selenium on a very thin plate of some metal with which it could enter into a kind of chemical combination, at least to such an extent as to permit it to adhere to the plate. In this manner the selenium plate is provided with a backing of good conducting metal, and therefore has its electric resistance greatly

Method employed by Fritts in forming selenium cells.

decreased. While the plate was cooling, and, consequently, undergoing crystallization, it was subjected to pressure applied against a plate of steel, or some other metal with which it could not enter into combination. By these means, on the removal of the steel plate, Fritts obtained a thin plate of selenium in a granular or crystalline condition, uniformly polarized as regards the condition of its opposite faces, and fairly conducting by reason of the metallic backing provided by the thin sheet of metal with which it entered into partial combination. At the same time, when the non-adherent plate of steel was removed from the free selenium surface, this surface was covered with a plate of gold, so thin as to readily permit light to pass through it, and so fall on the free selenium surface. Properties of the Fritts selenium cells.

Selenium cells as prepared by Fritts are, it is claimed, far more sensitive to light, and produce better results, than those made by any pre-existing process. When compared with cells prepared by Dr. Werner Siemens, which were, probably, the best of pre-existing cells, the following results were obtained. While the Siemens cells were some 14.8 times more conducting in sunlight than in the dark, those made by the Fritts process were 337 times more conducting in light than in the dark. Comparison between the Fritts and the Siemens selenium cells.

In order to obtain the best results by the Fritts process, it is necessary that the cell be protected from light when not in use. It must not, however, be inferred from this that the cells act best when but little used. On the contrary, the best results are obtained when the cells are in daily use, provided necessary intervals of rest are given to them. Rest necessary for proper action of selenium cells.

The Fritts selenium cell is subject to a marked decrease in electric resistance. It sometimes changes

Electric resistance of Fritts selenium cell.

from a high resistance of 200,000 ohms to the value of but a few ohms. The cell is most sensitive to light when its normal resistance is high. A cell whose resistance has become abnormally low can be restored to its ordinary resistance; *i.e.*, to its ability to act as a selenium cell, by the passage of an alternating current through it.

Bidwell's investigations.

In a series of investigations by Mr. Bidwell, published in the "Philosophical Transactions" for September, 1895, the conclusion is reached that the electric conductivity of selenium depends principally upon the presence of impurities in the selenium, and that such impurities consist principally of metallic selenides, such, for example, as a selenide of copper. He also concludes that it is due to the presence of these selenides that the plate conducts electrolytically, the action of light being to increase the ease with which the selenium enters into chemical combination with the metals. He points out the fact that the specific resistance of selenium, that is, its resistance per unit of length and area of cross-section, is very high, and that it is not by prolonged heating that a mass of selenium is made better conducting, unless it is at the same time in contact with a plate of metal, such as copper, with which it can enter into combination. In order to test this conclusion, he found that a selenium cell, the plates of which contained a mechanical admixture of 3% of the selenide of copper, would produce a cell which acted better, both as regards conductivity, and sensitiveness to light, than another cell made from ordinary selenium, that had been annealed for several hours, while not in contact with a substance with which it could combine. He finds that crystalline selenium is porous, and is capable of absorbing moisture from the air, and believes

Action of selenium cell dependent on presence of selenides.

Moisture absorbed from air by porous crystalline selenium.

that this moisture acts to decrease the electric resistance.

Bearing in mind that light is an electro-magnetic radiation, attention has been called to the similarity between the decrease that occurs in the electric resistance of a selenium plate on exposure to sunlight, and the decrease in the resistance of the coherer employed in the receiving apparatus in wireless telegraphy. It has been suggested that possibly this decrease in resistance is similar to that which occurs in wireless telegraphic apparatus by the coherence of the metallic filings of the coherer. This, however, is only a suggestion, and, we believe, no experimental evidence has been adduced in its favor.

Photo-electric batteries.

Photo-electric cells, of the Fritts type, can be made to act as electric generators, and can be coupled together in multiple as photo-electric batteries. Such photo batteries will produce electric currents by mere exposure to light. These currents result as a conversion of light energy into electric energy, the current immediately appearing as soon as the light falls on the face of the cell, and disappearing as soon as the light is removed.

How comparatively low electric resistance is obtained in selenium cells.

The high resistance of the selenium cell makes it necessary to obtain a short length of material, together with a great area of cross-section. By employing very thin plates of selenium between plates of copper and gold, as has already been described, Fritts obtained cells, the terminals of which consisted of conductors connected with the plates of gold and copper. The decrease in the resistance of a selenium cell can also be obtained by the arrangement shown in Fig. 152. Here the selenium is placed in a thin layer between two brass wires,

a and *b*. By connecting the ends of *a* to the metal plate *d d*, and the ends of the *b* to the metal plate *c c*, there is ensured a comparatively great extent of selenium coupled with small thickness.

Use of selenium cells in the photophone.

Selenium cells are suitable for use in connection with the photophone, an instrument by means of which conversation can be carried on along rays

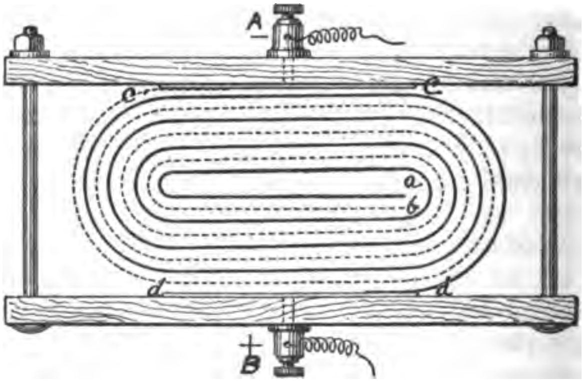
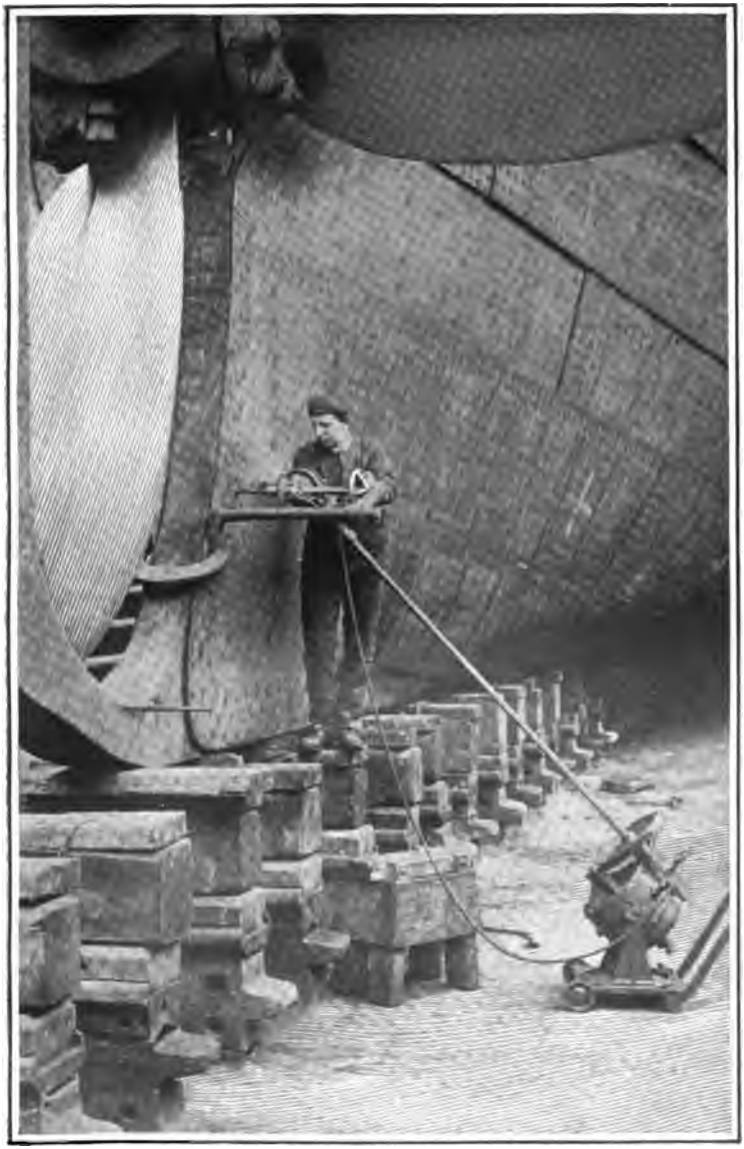


FIG. 152.—Mercadier's Photo-Electric or Selenium Cell. The binding posts A and B are connected respectively with the metallic plates *c c* and *d d*.

of light. We will describe this instrument in connection with the telephone in a subsequent volume.

Selenium photometer

The fact that a selenium cell is capable of transforming the energy of light direct into electric energy, has been utilized in the construction of a photometer, the name given to an instrument for measuring the intensity of the light emitted by any source. Photometers are employed when it is desired to ascertain whether the intensity of the electric or gas light, sold by different companies to consumers, comes up to the legal requirements. In the selenium photometer the intensity of the light is measured by permitting the light to fall on the



By courtesy of the "Scientific American"

PORTABLE ELECTRIC DRILL, USED IN SHIPBUILDING

"Mahomet and the Mountain" is now re-enacted in many shops and shipyards. The motor-driven machine tool is carried to the work where the latter can not be brought to the tool

surface of a photo-electric cell, and then determining the strength of the current so produced by the deflection of the needle of a galvanometer through whose coils this current has been caused to pass. In another form of selenium photometer the intensity of an unknown source of light is compared with that of the standard light, by comparing the strength of the photo-electric current produced by each, by means of the deflections they respectively cause in the needle of a galvanometer.

Automatic photo-electric regulator of electric light.

The photo-electric cell has been employed in a variety of automatic apparatus. Among such may be mentioned an automatic regulator for maintaining constant the intensity of an electric light produced by an incandescent lamp, operated by a battery current. The battery furnishing the lighting current is provided with a switch, whose movement in one direction under the action of a spring, increases the strength of the battery current, and whose movement in the opposite direction, under the action of an electro-magnet, decreases the current strength by the introduction of electric resistances into its circuit. The electro-magnet is operated by photo-electric currents generated by the light from the lamp falling on the face of a photo-electric cell. If now matters are so arranged that when the light is of the desired amount, the spring and the electro-magnet balance each other, the switch is unaffected; but if too much light is produced, then, the photo-electric current being increased, the electro-magnet so moves the switch as to decrease the current; while, on the contrary, if the amount of light becomes too feeble, the spring moves the switch so as to increase the current. In this way an automatic regulation of the voltaic battery is effected, so that the light it produces remains constant.

Photo-electric currents.

Another curious device obtained by means of the photo-electric cell takes the form of an apparatus sometimes called the selenium eye, from the fact that, like the human eye, it can automatically regulate the quantity of light that passes through it. As is well known, the human eye is capable of thus regulating the quantity of light that enters it, by an automatic opening and closing of the pupil. If too much light enters the eye the pupil contracts; if too little enters it, the pupil dilates, or opens, so that the amount of light is maintained approximately constant. Now, in the artificial selenium eye, a shutter is so devised as to be able, by the movements of an electro-magnet, to be opened and closed in a manner similar to the dilatation and contraction of the pupil of the eye. A selenium cell is placed inside a chamber provided with such a shutter. If too much light enters this chamber, the photo-electric current thereby produced causes the electro-magnet to partially close the shutter. If too little light enters the chamber, the decrease in the strength of the photo-electric current permits a spring connected with the electro-magnet to partially open the shutter, and thus let in more light.

Selenium eye.

How the selenium eye or automatic diaphragm operates.

Another very curious device is found in the selenium burglar-alarm, in which a burglar automatically reveals his presence in a building at night by means of electric currents generated by the light of his dark lantern falling on the face of a photo-electric cell. The current produced in this manner is caused to sound an alarm in a neighboring police station, the burglar thus unwittingly calling the police to arrest him.

Selenium burglar alarm.

We will mention but one more of a number of equally curious applications of the photo-electric

cell. This consists of a device for automatically turning on an electric light, at the approach of night, and turning it off at the approach of day. This is accomplished by means of an electro-magnet operated by the photo-electric currents produced by light, the increasing light of day producing a current sufficiently strong to open a switch, thus cutting off the electric light, while the decrease in the strength of the current, on the approach of night, permits a spring to close such circuit and light the lamp.

Automatic day and night switch.

CHAPTER XXVII

SOME OTHER FORMS OF CELLS

"Lippmann has observed that the capillary effects manifested between mercury and acidulated water depend on the difference of potential of the two liquids, and conversely that the difference of potential of the liquids is modified when the magnitude of the surface of contact is changed by external forces."—*Electricity and Magnetism:* MASCART AND JOUBERT

Cells other than chemical, heat, and light cells.

IN addition to the various electric cells already described for producing electric current by the conversion of chemical, thermal or luminous energy into electric energy, there are a number of other cells that it will be well to describe, before leaving this part of the subject of the generation of the electric current.

Osmose, or the unequal mixing of two liquids through a porous wall permeable to both.

It might naturally be thought that when two liquids of different densities, which are capable of mixing with each other, are placed in vessels communicating by means of a porous wall or partition, through which both liquids can pass, that the mixing will take place equally through the separating wall. This, however, is not so. A greater quantity of one of the liquids than of the other will pass, so that, although their upper surfaces were on the same level, or equal at the start, the level of one of the liquids soon rises considerably above that of the other. This phenomenon is called osmose.

If a solution of sugar and water be placed in a moist pig's bladder, B, Fig. 153, the neck of which

is securely fastened to a straight glass tube, T, and the bladder be then immersed in a vessel, V, of pure water, so that the level of the sugar and water in the glass tube is the same as the level of the pure water in the glass vessel, the liquids will begin to mix by osmose, the sugar and water passing through the pores of the bladder into the pure water in the outer vessel, and the pure water passing into the

Osmotic mixture of pure water and sugar solution.

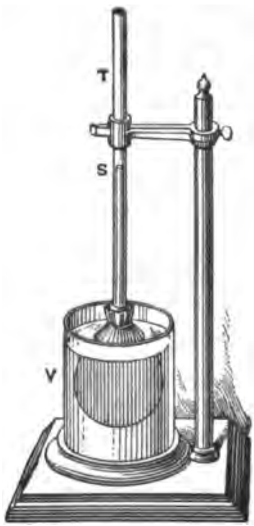


FIG. 153.—Phenomena of Osmose of Liquids. Note the fact that here the denser liquid, the sugar solution, mounts above the less dense liquid, the pure water.

sugar and water in the bladder. The latter current, however, is the stronger of the two, as will be seen by the surface of the liquid gradually mounting in the glass tube to some point, S, above the level of the water in the glass vessel.

Porret found that when a fairly strong electric current is sent, under the above circumstances, through a porous partition from one liquid to the

Porret's discovery of electric osmose.

other, a portion of the liquid is carried mechanically along with the current, so that the level rises on the side toward which the electric current flows. Since the current flows from the positive to the negative terminal, the higher level of the liquid will be found on the side connected with the negative terminal; *i.e.*, more liquid will be found on the side connected with the cathode, than on the side connected with the anode. This phenomenon is called electric osmose, in order to distinguish it from the ordinary osmose, above referred to. The difference in the liquid levels so produced is most marked in cases where poorly conducting liquids are employed, such as bi-sulphide of carbon and alcohol.

Electric osmose most marked in poorly conducting liquids.

As the converse of this proposition, Quincke, in 1859, discovered that when one of the liquids in the preceding device is forced, by pressure, through the porous partition, or diaphragm, as it is sometimes called, electric currents are thereby produced. These currents are called diaphragm currents. The electro-motive forces produced in this way depend on the character of the liquids employed, on the material of which the diaphragm is composed, and on the amount of the pressure that forces the liquid through the pores of the diaphragm. Electro-motive forces as great as nine volts can be obtained by forcing water under the pressure of fifteen pounds to the square inch through a plate of sulphur. Here, then, we have another electric source in which mechanical energy is changed into electric energy, a portion of the energy required to force the liquid through its pores in the diaphragm appearing as electric energy.

Quincke's discovery of diaphragm currents.

The phenomena of diaphragm currents and electric osmose are connected with the passage of liquids through the short capillary or fine, hair-like tubes

that form the pores of the diaphragms. Lippmann, Dewar, and others, have made a careful study of the electric and mechanical effects produced in capillary tubes under certain conditions, and have studied the conditions under which the passage of electric currents sets up a flow of liquids through capillary tubes, and, conversely, the forced flow of liquids through capillary tubes sets up electric currents.

Lippmann and Dewar on electric currents produced by forcing liquid through capillary tubes.

When a globule of mercury is placed below a surface of sulphuric acid diluted with water, electromotive forces are produced by the contact of the mercury and the acid solution, so that certain differences of electric pressures are produced between the mercury and the acid solution. The two surfaces, however, do not actually touch each other, but are separated by a very small space. Consequently, the globule of mercury, and the liquid which surrounds it, act as a minute Leyden jar, or condenser, the capacity of which, though small, is definite. The globule of mercury possesses a certain surface tension, which may be varied mechanically either by shaking the globule, or by moving it from one place to another, and any of these changes will alter the capacity of the miniature Leyden jar. The passage of an electric current will also cause a variation in the surface tension, that will be accompanied by a movement of the globule. The device, therefore, is capable of converting either mechanical energy into electric energy, or electric energy into mechanical energy.

Contact E.M.F.'s produced by mercury immersed in dilute sulphuric acid.

Mercury globules as current generators.

If an iron wire be dipped below the surface of the dilute sulphuric acid, referred to above, so as to just touch the globule of mercury on one side, a change in the shape of the globule, due to differences of potential caused by contact, will take

Mercury globule, automatic circuit breaker.

place, the globule becoming more rounded. This change causes the globule to draw itself away from the wire, thus breaking contact with it. The globule then is flattened out by gravity and again touching the wire, alters in shape and thus again breaks its circuit. In this manner an automatic opening and closing of the circuit will thus be set up and maintained for a considerable length of time. Interrupters for automatically opening and closing an electric circuit have been constructed on similar principles.

Dewar's capillary electrometer.

Very sensitive capillary electrometers have been devised by Lippmann, Dewar, and others, on the above principle. Dewar's form of such an electrometer is shown in Fig. 154. Here, a horizontal

FIG. 154.—Dewar's Capillary Electrometer.

glass tube has its free ends immersed in two vessels, M and N, filled with mercury, and is itself filled with mercury, except the small quantity of dilute sulphuric acid shown at B. If an electric current be sent through the tube by means of the conducting wires that are shown dipping into the mercury in the two vessels, a movement of the drop of acid will take place toward the negative pole of the circuit. Where the electro-motive force employed does not exceed one volt, the amount of these movements increases with the value of the electro-motive forces applied, so that the apparatus is capable of being used as an electrometer. Electro-capillary electrometers are so exceedingly sensitive

Great sensibility of capillary electrometers.

that they are capable of measuring the one-ten-thousandth of a volt.

A form of capillary electrometer devised by Lippmann is shown in Fig. 155. It consists of a glass tube, A, the lower extremity of which is of very fine bore or internal diameter; *i.e.*, of capillary or hair-like dimensions. This tube is partly filled with mercury and dipped below the surface of mercury contained in the vessel B. Dilute sulphuric acid is placed in B, and rests on the surface of the mercury

Lippmann's capillary electrometer.

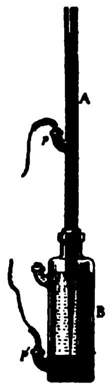


FIG. 155.—Lippmann's Capillary Electrometer.

in the lower part of B. Under these circumstances the mercury is kept at a certain height, A, by the surface tension of the mercury at the capillary or lower end of the glass tube. On the passage of a current through the instrument, by connection of an electric source with the conducting wires at p and p', a movement of the mercury column in A will take place; and, from the extent of this movement the value of the electro-motive force can be determined.

Some experiments made in 1855, by Krouchkoll, show that when mercury is driven through metallic **Krouchkoll**

E.M.F.'s produced by forcing mercury through metallic capillary tubes.

capillary tubes, electric currents may be produced, provided very high pressures are employed; *i.e.*, pressures above fifteen atmospheres.

Balsamo's magneto-chemical cell.

In 1867, Balsamo produced weak electric currents by means of what he called a magneto-chemical cell. This cell consists of two magnetized steel bars of the same size, construction, and condition of surface, whose north and south poles are respectively immersed in a solution of oxalic acid.

Impulsion cell.

Another curious form of cell is found in what is sometimes called an impulsion cell. It consists of a variety of photo-electric cell whose sensitiveness to light may be either destroyed or restored by slight impulses given to the plates, as by blows, taps, or electro-magnetic impulses. A form of impulsion cell is shown in Fig. 156. Here a glass tube, A B,

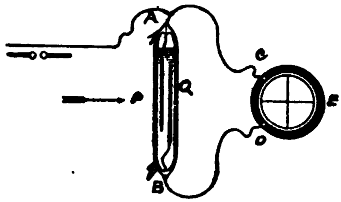


FIG. 156.—Impulsion Cell, a peculiar variety of photo-electric or selenium cell.

filled with methylic alcohol is provided with two aluminium plates, P and Q, connected to platinum wires *p* and *q*, connected with the terminals or electrodes, A and B, of the cell. The surface of one of the aluminium plates, P, is covered with a thin layer of selenium, sensitive to the action of light; while the other plate, Q, is left as a clean plate of aluminium. When the sensitive plate is exposed to light, the production of a photo-electro-motive force is indicated by the movement of the spot of light from the

mirror of the electrometer, E, connected by conducting wires with the terminals of the impulsion cell. If at any time while the cell is in a sensitive condition, a slight tap, blow, or impulse be given it, as for example, by a single gentle tap, the cell will instantly lose its sensitiveness to light. But if, after resting in the dark for an hour of so, another slight tap be given to it, the cell will again instantly regain its sensitiveness to light. Thus opposite conditions or changes can be obtained in this manner by successive taps, for an indefinite number of times. Origin of name impulsion cell

It is interesting to note in this connection that if a disruptive discharge be made in the neighbor-

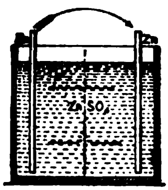


FIG. 157.—Concentration cell.

hood of an impulsion cell, so that the violet rays of the spark may fall on the sensitive selenium plate, it will at once restore the sensitive condition to a cell that has lost its sensitiveness. Action of violet light on impulsion cell

There is still another manner in which electric energy may be obtained from a cell in which the only change that takes place is a change in the degree of concentration of the solutions in which the electrodes dip or are immersed. Such a cell, called a concentration cell, is shown in Fig. 157. It consists of two plates of metallic zinc immersed in concentrated and dilute solutions of sulphate of zinc, separated from each other by a suitable porous diaphragm. Under

these circumstances, an electric current is produced, whose direction is indicated by the feathered arrows. During action changes occur by means of which the dilute solution tends to become more concentrated, and the concentrated solution tends to become more dilute. The exact manner in which the electromotive forces are produced in concentration cells has not as yet been fully determined. The E.M.F.'s are not due to chemical actions since no chemical

Concentration cell.

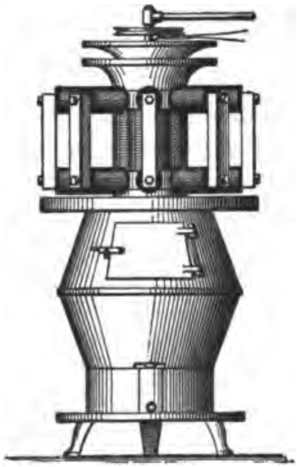


FIG. 158.—Edison's Pyro-magnetic Generator. Much was expected from this device in the way of cheap electric current. It has now taken its place, however, among the many similar devices that have been weighed in the balance of actual trial and found wanting.

solution occurs in either plate, the only change being in the degree of concentration of the liquid.

Edison's pyro-magnetic generator.

A generator, capable of producing electric currents, under the combined influence of heat and magnetism, is shown in Fig. 158. This generator is an invention of Edison, and is called the pyro-magnetic generator. It consists of an armature formed of eight electro-magnets, each of which is

provided with the usual coils of insulated wire, wrapped around cones of iron and nickel, and protected by a covering of asbestos paper. By means of a belt, acting on a pulley, this armature is caused to rotate between the poles of electro-magnets. The heat of a fire in a stove is caused to heat one-half of the iron armature, by the action of a guard plate that, during rotation, cuts off the heat from one-half of the armature. These differences in temperature cause differences in the quantity of magnetic flux that passes through the coils of wire on the armature, and so produce electro-motive forces therein. The apparatus, therefore, operates in a manner somewhat similar to the ordinary dynamo-electric machine. It forms one of the many devices that have been produced in the attempt to obtain electricity directly from the burning of coal in air. The pyro-magnetic generator is unfortunately not a commercial success.

Living animals and plants as electric sources.

Living animals and plants are to be regarded as electric sources. The existence of electric currents in living animals can readily be demonstrated. We do not mean in such special animals as the electric ray, torpedo or eel, but all ordinary animals. We have already seen how Galvani deceived himself, in believing that in his famous experiments with the frog's legs, he had actually demonstrated the existence of electric currents. Afterward, however, though by other means, both Galvani, Aldini, Nobili, Matteucci, Du Bois-Reymond, and others, proved conclusively that electric currents exist in all living animals. Nobili demonstrated that when the nerves and the muscles of a recently killed frog were connected under conditions in which no chemical action was possible, an electric current was produced, and even made a series battery of such elements, by suitably connecting them so as to augment the

Experiments of Galvani, Aldini, Matteucci and Du Bois-Reymond on the electricity of animals.

electro-motive force, and, consequently, increase the total current produced.

Experiments of Matteucci and Du Bois-Reymond.

Experiments made by Becquerel and Matteucci demonstrate that when the muscles of living animals are strongly contracted electric currents are thereby produced. Matteucci succeeded in producing contractions in the muscles of a recently killed frog, by means of electric currents produced by contractions in the body of a living frog. Du Bois-Reymond also produced electric currents by the muscular contractions of his arms. By connecting the terminals of a sensitive galvanometer with saline solutions placed in two glass vessels, and then dipping the tips of his fingers in such solutions, after strong contraction of the muscles of his arms, the needle of the galvanometer was deflected, showing that electric currents were thereby produced.

As was quite natural in so difficult a subject, much difference of opinion existed as to the causes of the electric currents present in the bodies of healthy animals during the conditions of ordinary life. De la Rive, who has given this matter much careful study, thus gives his opinion and that of Matteucci. It will be seen that De la Rive agrees only in some respects with the latter philosopher:

De la Rive on cause of animal electricity.

"It follows, from the detailed study, that we have just been giving, that the body of a living animal may be regarded as the seat of an innumerable multitude of electric currents, the greater portion of them having only local circuits; it is the derived portions of these currents that we succeed in collecting by experiment. But, when, by the effect of the will, or of another cause acting directly upon the nerve, its electric state is modified, the corresponding local current is transformed, if not entirely, at least in

part, into a current, the more considerable circuit of which comprehends then the nerve and the corresponding muscle; and the effects, that we have been pointing out, result from it.

"We shall not quit this subject without remarking, that we are led to assume that the agent by means of which all nervous action is exerted is electricity; not an electricity created at the very moment when the nerve acts, but pre-existing in all the organic particles, as it pre-exists in all the particles of inorganic matter. We are, moreover, forced to admit that, under the influence of life, these particles are arranged in an altogether special manner, and which permits of the accomplishment of the organic functions; so that life can not be considered as a consequence of the electric nature and of the arrangement of these particles, but must, on the contrary, be regarded as the cause of their mode of grouping, and consequently indirectly of the phenomena that result from it. Let life indeed be taken away, and the particles, still preserving their electric properties—that is to say, their polarity,—are grouped quite differently, so as to obey the conditions of equilibrium of the forces that are proper to them, and no longer present aught but the ordinary phenomena that inorganic matter offers us.

Life not the result of electric currents.

"M. Matteucci, while still recognizing that organic currents are not due to any exterior chemical action whatever, considers that we must attribute them to the chemical actions of the living organism. It would, according to him, be in the chemical action that must exist between muscular fibre, properly so called, and arterial blood in contact with it, and consequently in the nutritive life of the tissues, that we ought to seek for the cause of the currents. It would be thus inherent in the state of life of the organic tissues, and constantly connected with a

Electric currents produced by action of blood on muscular tissues.

difference in the state and in the nutritive power of these tissues, so that the positive element of the organic pair would be always represented by the part of the tissue whose nutritive power is the stronger. As is apparent, M. Matteucci agrees with us in this point, that it is from the vital force that he makes animal electricity depend in the first instance; only, according to him, it is only indirectly in compelling nutrition to operate that the nerves, intermediate between vital force and the muscles, would develop electricity, whilst, according to us, the action would be more direct; the transmission of vital action from the nerves to the muscles being brought about by the very electricity with which the nerves are primitively endowed. We shall in no way contest the part of chemical action in the production of animal electricity; but it is not from it that we make the first origin of this electricity proceed, which we think, as we have just said, to be pre-existent to the causes that determine its manifestation, as well in the living organism as when inorganic matter is in question."

Matteucci's near agreement with De la Rive.

That electricity is produced in plants during periods of growth, has been proved by a great number of investigators. In 1850, Wartmann published the following conclusions as the results of investigations made by him, extending over two years:

Wartmann on the electricity produced by plants during their growth.

"1. Electric currents are to be detected in all parts of vegetables but those furnished with isolating substances, old bark, etc., etc.

"2. These currents occur at all times and seasons, and even when the portion examined is separated from the body of the plant, as long as it continues moist.

"3. In the roots, stems, branches, petioles, and peduncles, there exists a central descending, and a

peripherical ascending current: Wartmann calls them axial currents.

"4. On connecting, by means of the galvanometer, the layers of the stem where the liber and the alburnum touch, either with the most central parts (pith and perfect wood) or with the most external parts (young bark), lateral currents passing from these layers to surrounding parts have been detected. Bark currents.

"5. In the leaf the current passes from the lamina to the nerves, as well as through the central parts of the petiole and the stalk. Leaf currents.

"6. In the flowers the currents are feeble. They are very marked in the succulent fruits, and in some kinds of grain; the currents from the fruits proceeding in most cases from the superficial parts to the adjacent organs. The strength of the current depends on the season; they are greatest in the spring, when the plant is bathed in sap. Flower currents.

"7. Currents can also be detected proceeding from the plant to the soil, which is thus positive with relation to it, and currents are also manifested when two distinct plants are placed in the circuit of the rheometer." Currents from plant to soil.

CHAPTER XXVIII

THE DISCOVERY OF THE PRODUCTION OF MAGNETISM BY ELECTRICITY

"Fortune, it may be said, ceased to be blind at the moment when to Oersted was allotted the privilege of first divining that it was not electricity in repose, accumulated at the two poles of a charged battery, but electricity in movement along a conductor by which one of the poles is discharged into the other, which would exert an action on a magnetized needle. When thinking of this—it was during the animation of a lecture before the assembled pupils—Oersted announces to them what he is about to try; he takes a magnetized needle, places it near the electric battery, waits until the needle has arrived at a state of rest; then, seizing the conjunctive wire traversed by the current of the battery, he places it above the magnetic needle, carefully avoiding any manner of collision. The needle—every one plainly sees it—the needle is at once in motion. The question is resolved. Oersted has crowned by a great discovery the labors of a whole previous life."
—*Memoir of Oersted:* Elie de Beaumont

Discoveries that stand like giant mountain-peaks among the surrounding elevations.

IN the history of electricity and magnetism there are certain discoveries which, by reason of their far-reaching results, stand out like great mountain peaks among the smaller mountains and hills that represent less important discoveries. We have already alluded to some of these discoveries, such, for example, as that made by Franklin, concerning the identity of lightning and electric discharges; that made by Volta, of the voltaic cell; and that made by Daniell, of the constant voltaic cell. We have now to study two discoveries somewhat allied to one another, that are indeed giants that stand by themselves. We allude to the discovery of the production of magnetism by elec-

tricity, made by Oersted, in 1819, and the discovery, at a later date, by Faraday, of the production of electricity by magnetism. As we shall see, there have probably never been discoveries made in electricity or magnetism that have produced such far-reaching results.

Reasons for belief in some relations between electricity and magnetism.

It was generally suspected by scientific men for many years prior to 1819, that some relation exists between electricity and magnetism. It was pointed out that there are two electricities and two magnetisms, and that there are attractions and repulsions in the case of both. Many attempts were therefore made to establish this suspected identity by experiment. For example, in 1805, Hatchett and Desormes endeavored to cause an insulated voltaic battery to point to the earth's magnetic pole, as a magnetic needle would do. Since, however, the circuit of this battery was opened, they were unsuccessful. Until the time of Oersted all such experiments were made with voltaic batteries on open circuit, or when they were producing no electric current, and were therefore futile.

Prof. Hans Christian Oersted.

Hans Christian Oersted, a professor in the University of Copenhagen, while engaged in an extended series of experiments carried on for the purpose of discovering the relation between electricity and magnetism, closed the circuit of the voltaic battery, and found the long-sought-for relation. This, as may be seen from the quotation at the chapter heading, was done during a lecture at the university.

Nature of Oersted's discovery.

Oersted's discovery consisted in the fact that it is only while flowing through some conducting path that electricity manifests magnetic power. He showed that any conductor, no matter what its

character, while conveying an electric current thereby becomes a magnet, and will, like any other magnet, deflect a magnetic needle in its neighborhood.

Oersted's original experiment.

Oersted's original experiment is readily repeated by means of the simple apparatus shown in connection with Fig. 159. Here a copper wire is held horizontally over a magnetic needle, N S, in the same direction as that in which the needle has come to rest under the influence of the earth's magnetism. So long as no current is flowing through this conducting wire the needle will remain in its position; but, as soon as a current is passed, say in the direction indicated by the large arrow, from plus to

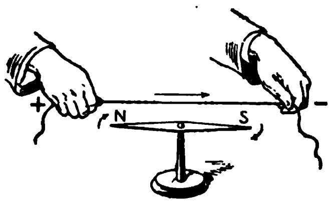


FIG. 159.—Oersted's great discovery of the production of magnetism by electricity.

minus, the needle will be deflected in the direction indicated by the smaller curved arrows. It can be shown that, while the current is passing through the conductor held above the needle in a direction, say from north to south, it will cause the north pole of the needle to be turned toward the east; while if, in this position, it is passed through the conductor in the opposite direction, or from south to north, the north end of the needle will be deflected to the west.

Davy's announcement of Oersted's discovery.

Oersted's discovery produced great excitement in the scientific world, and his experiments were repeated by many scientific men. Sir Humphry

Davy in a communication to the Royal Society of London, on November 16, 1820, referred to some of his own experiments in this direction, when he announced Oersted's discovery to the Society:

"The similarity of the laws of electrical and magnetic attraction has often impressed philosophers; and many years ago in the progress of the discoveries made with the voltaic pile, some inquirers (particularly M. Ritter) attempted to establish the existence of an identity or intimate relation between these two powers; but their views being generally obscure, or their experiments inaccurate, they were neglected; the chemical and electrical phenomena exhibited by the wonderful combination of Volta, at that time almost entirely absorbed the attention of scientific men; and the discovery of the fact of the true connection between electricity and magnetism, seems to have been reserved for M. Oersted, and for the present year.

Davy's communication to the Royal Society of London.

"This discovery, from its importance, and unexpected nature, cannot fail to awaken a strong interest in the scientific world; and it opens a new field of inquiry into which many experimenters will undoubtedly enter: and where there are so many objects of research obvious, it is scarcely possible that similar facts should not be observed by different persons. The progress of science is, however, always promoted by a speedy publication of experiments; hence though it is probable that the phenomena which I have observed may have been discovered before, or at the same time, in other parts of Europe, yet I shall not hesitate to communicate them to you, and through you to the Royal Society.

Scientific progress promoted by publication of results obtained.

"I found, in repeating the experiments of M. Oersted with a voltaic apparatus of one hundred pairs of plates of four inches, that the south pole of a common magnetic needle (suspended in the

usual way) placed under the communicating wire of platinum (the positive end of the apparatus being on the right hand) was strongly attracted by the wire, and remained in contact with it, so as entirely to alter the direction of the needle, and to overcome the magnetism of the earth. This I could only explain by supposing that the wire itself became magnetic during the passage of the electricity through it, and direct experiments which I immediately made proved that this was the case. I threw some iron filings on a paper, and brought them near the communicating wire, when immediately they were attracted by the wire, and adhered to it in considerable quantities, forming a mass round it ten or twelve times the thickness of the wire: on breaking the communication, they instantly fell off, proving that the magnetic effect depended entirely on the passage of the electricity through the wire. I tried the same experiment on different parts of the wire, which was seven or eight feet in length, and about the twentieth of an inch in diameter, and I found that the iron filings were everywhere attracted by it; and making the communication with wires between different parts of the battery, I found that iron filings were attracted, and the magnetic needle affected in every part of the circuit."

Conducting wire rendered magnetic by passage of the electric current.

The reference made by Davy, in the communication above referred to, as to the accumulation of iron filings around a conductor traversed by an electric current, shows that the conductor has a magnetic field produced around it. The presence of this field and the general direction of its lines of magnetic force, can be shown by passing the wire conveying the current through a sheet of stiff paper, held in a horizontal position, and sprinkling

Magnetic fields produced around electric conductor by the passage of an electric current.

iron filings over its surface. Under these circumstances, when the paper is slightly tapped, the filings will arrange themselves in concentric circles around the conductor, as shown in Fig. 160. It is evident, therefore, that the passage of an electric current

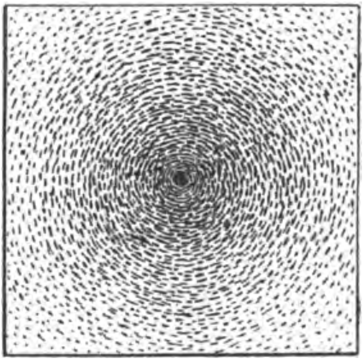


FIG. 160.—Magnetic Field produced around conducting wire by the passage of an electric current.

produces, in a manner which is yet unknown, magnetic whirls around the axis of the conductor, as shown in this figure.

In order to remember the direction in which a magnetic needle will be deflected by a conductor carrying an electric current, various rules have been proposed. One of these, proposed by Ampère, is as follows: "Imagine yourself swimming in the conductor in the direction of the current, with your face turned toward the needle. Then the north pole of the needle will always be deflected toward your left hand." Another rule, proposed by Maxwell, is as follows: "Regard the current as flowing in the direction in which an ordinary corkscrew is advancing. Then the direction of the circular lines of force will be the same as the direction in which the screw

Ampere's rule for direction of deflection of magnetic needle by an active conductor.

Maxwell's rule for determining direction of lines of force.

turns." For example, the direction of the lines of magnetic force produced by the current flowing through the conductor DD, Fig. 161, in the direction indicated by the arrow, from north to south, is that indicated by the curved arrows. Here it will be seen that this is the same direction as that in which a

Screw rule.

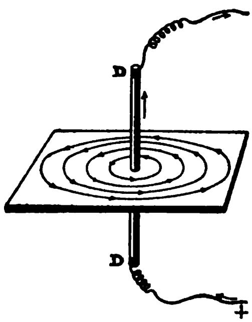


FIG. 161.—Direction of circular lines of magnetic force of conductor traversed by electric current.

screw would require to be turned in order to advance in the direction taken by the current in flowing through DD.

Coming now again to the original experiment of Oersted, and holding the conducting wire over the magnetic needle, as shown in Fig. 159, pass the current through it in any direction, and note the direction in which the needle is deflected. Now bend the wire into a loop, so that the current must flow through the conductor below the needle in the opposite direction from what it does in the direction above, and note that the needle is more powerfully deflected than when the current only passes above the needle. Now bend the wire so that it will take the shape of the hollow rectangular circuit, shown in Fig. 162, and passing the current through

Increased deflection of needle by conducting loop.

LIFTING PIG IRON WITH AN ELECTRO-MAGNET

The crane here shown carries a powerful electro-magnet, which, when excited by an electric current, picks up heavy iron "pigs" as a toy magnet does iron filings. Cranes equipped with lifting magnets handle steel plates, castings, pig iron, etc., very expeditiously

it by connecting the ends of the wire P and N, with the positive and negative poles respectively of an electric source, note that the needle NS is now deflected more than in either of the preceding experiments.

It can be shown by experiment that, not only those portions of the conductor which are above and below the magnetic needle tend to deflect it in the same direction, but that also the two smaller portions where the current is passing respectively down and up, as shown in the figure by the arrows at the end, also deflect the needle in the same direction. In other words, a conductor bent in the form of a hollow

Conjoint and similarly directed action of all parts of an active rectangular loop on magnet.

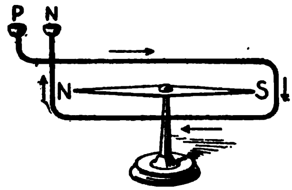


FIG. 162.—Similarly directed action of all parts of an active rectangular circuit on magnetic needle placed inside such circuit.

rectangle, as shown in Fig. 162, has all parts of its circuit acting to produce a deflection of the magnetic needle placed within it in the same direction. Such an instrument was formerly called the multiplier, because the hollow rectangular circuit multiplies the action of the conducting wire, and tends more powerfully to deflect the needle. The principle of the multiplier was invented by Schweigger, in 1820, not long after the announcement by Oersted of the production of magnetism from electricity. A Schweigger multiplier is shown in Fig. 163. It consists of a copper wire, carefully insulated by a covering of cotton or silk, and bent in the form of a hollow rectangle so that a number of successive turns are

Schweigger's invention of the multiplier the forerunner of the galvanometer.

produced, as shown in the figure. By this arrangement the current, instead of passing but once around a magnetic needle suitably supported in the centre of the rectangle, is passed a number of times around such needle, so that the effect produced by each turn is multiplied in proportion to the number of turns. In this way a comparatively feeble current is able to produce a sensible deflection of the needle. Galvanometers are operated on this principle.

Origin of word "multiplier."

Galvanometers are employed, as we have already mentioned, for the purpose of measuring the strength of an electric current by the deflection of

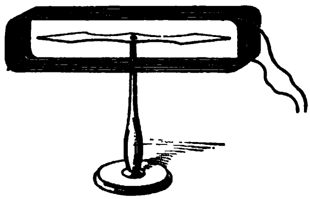


FIG. 163.—Schweigger Multiplier. A coil consisting of a number of parallel conducting loops of insulated wire exerts a far more powerful deflecting action on a magnetic needle than would a single loop carrying the same electric current. Note that, as shown in the figure, the magnetic needle is at rest in a north and south direction, and that no current is passing through the multiplier.

High-resistance galvanometers for small currents.

a magnetic needle. In extremely sensitive galvanometers the number of separate turns sometimes reaches many thousands. Such galvanometers, however, have a high electric resistance, so that they are, therefore, suitable only for measuring small currents produced by high electro-motive forces. Sometimes, however, where extremely large currents are to be measured, the galvanometer coil consists of but a single turn of a good conducting wire.

Low-resistance galvanometers for large currents.

When no current is passing through the galvanometer coils, its needle, when at rest, should occupy a

position parallel to the plane of the coil. On the passage of the current the needle tends to place itself at right angles to the length of the conducting wire of the galvanometer coils. From the amount of its deflection, measured in degrees on a graduated scale over which the needle moves, the strength of the current may be determined. Generally the magnetic needle is deflected by the current passing through the galvanometer coils from its position of rest in the earth's magnetic field. Sometimes, however, the field of a permanent or electro-magnet is employed instead of the earth's field. In the first case, when employed for measuring the strength of a current, the galvanometer coils must be placed

Relative position of galvanometer coils and needle.

Fields of permanent and electro-magnets used in galvanometers to replace earth's field.

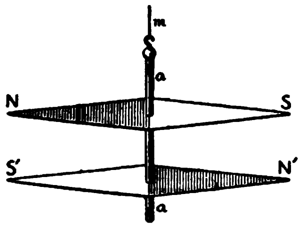


FIG. 164.—Astatic Galvanometer Needle. The hook for the suspending fibre is shown at *m*. Note that the opposite poles N S' and S N' are placed near one another, with their poles in the same vertical plane.

in such a position that the plane of the coils will coincide with the direction in which the needle comes to rest, so that the magnet, when at rest, shall be in a direction parallel to the direction of the galvanometer coils. When, however, the field of a permanent or electro-magnet is employed, the instrument may be used to measure the current strength when in any position in which the needle is free to move.

In order to obtain a very sensitive galvanometer, some device must be employed to lessen the directive

Astatic magnetic needle.

force which the earth's magnetism exerts on the galvanometer needle. One method of doing this is to employ what is called an astatic needle. Such a needle, as shown in Fig. 164, consists of two separate magnetic needles, N S and S′ N′, rigidly connected together by means of the axis *aa,* and placed parallel and directly over one another, so that their opposite poles are opposed. When so arranged, the needles, when placed in a magnetic field by a suspension fibre connected to the hook *m,* shown at the top of the system, will act as a single weak magnetic needle.

The astatic needle is placed so that the upper needle is outside the galvanometer coils, and the

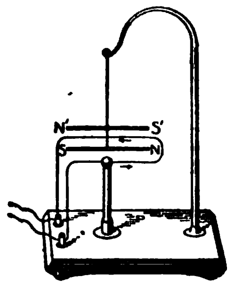


FIG. 165.—Astatic Needle with single turn of active conductor. Note here that the current passing through the upper part of the conductor deflects both N S and S′ N′ in the same direction, because their opposite poles face each other.

Use of astatic magnet in galvanometers.

lower needle is inside such coils. Under these circumstances, it is clear that the current passing through the galvanometer coils will flow above one needle and below the other, and that it will deflect both needles in the same direction. This will be seen from an inspection of Fig. 165, where the current which flows below the needle S′ N′ flows above the needle N S and therefore deflects them both in the same direction. In extremely sensitive galvanom-

eters two separate coils are sometimes employed, the upper and lower needles being placed respectively in separate coils. Under these circumstances, the coils must be oppositely connected in order that both needles may be deflected in the same direction.

Compensating magnet for galvanometer.

In some forms of galvanometers, a varying degree of sensitiveness may be obtained by the use of what is called a compensating magnet, placed on an axis above the magnetic needle. As the compensating magnet is moved toward or from the magnetic needle, the effect of the earth's field is varied, and with it the sensitiveness of the galvanometer. A

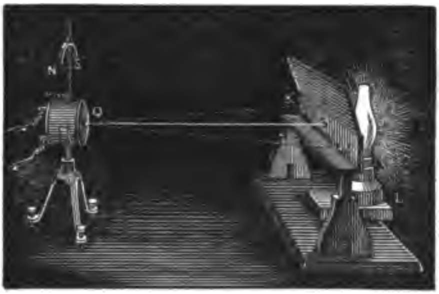


Fig. 166.—Kelvin's Mirror Galvanometer. The compensating magnet N S can be moved toward or away from the galvanometer needle

Some details of mirror galvanometer.

galvanometer provided with such a compensating magnet is shown in Fig. 166. This particular form of galvanometer shown here is sometimes called a mirror galvanometer, because, instead of reading the deflections of the magnetic needle directly, by their movements over a graduated dial, they are read indirectly, by the movements of a spot of light reflected from a small mirror attached to the magnetic needle. In the mirror galvanometer, shown in the figure as constructed by Kelvin, the needle is attached directly to the back of a light silver glass mirror, on the back of which the magnetic needle, consist-

ing of several small magnetized pieces of watch spring, is placed. In this galvanometer, the needle is suspended by a single silk fibre, and is placed inside the galvanometer coils. NS is the compensating magnet supported on an axis placed above the galvanometer magnet. The light of a lamp, L, placed before a slot in a screen, falls on a mirror, Q, which reflects it to the scale K, placed as shown.

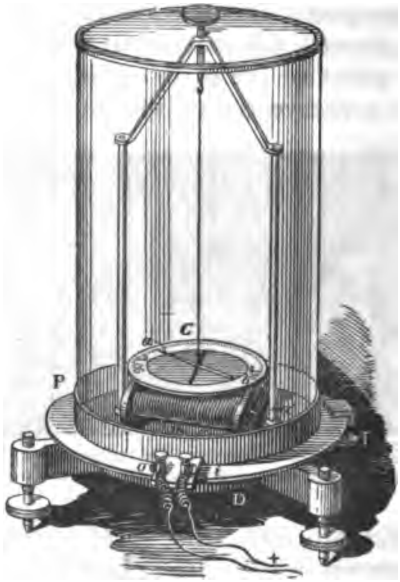


FIG. 167.—A form of Galvanometer, with an Astatic Magnetic Needle. Note the short pins extending above the face of the graduated scale, to prevent the needle from making a complete rotation, and thus unduly twisting the suspension fibre.

One form of galvanometer with an astatic magnetic needle.

A common form of galvanometer is shown in Fig. 167. Here the instrument rests on three levelling screws, provided to secure a true horizontal position for the instrument, and thereby a free movement of the needle within the coil. This galvanometer employs an astatic needle, the upper of

which, *ab,* only is shown on the outside of the galvanometer coil. The needle is suspended by means of a single silk fibre, and its deflections are read on the graduated scale shown immediately above the upper face of the galvanometer coil.

Almost immediately after the announcement by Oersted of his great discovery, Ampère, a distinguished French physicist, began a series of investigations concerning these phenomena. He showed, by means of many different experiments, that the magnetic force resides in all parts of the circuit, including not only the conducting wires, but even

Ampère's experimental investigation of Oersted discovery.

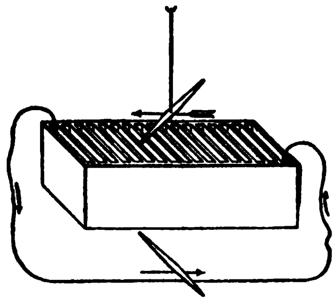


FIG. 168.—Ampère shows that a voltaic battery is magnetic as well as the rest of its conducting circuit.

the battery itself. This he showed by means of magnetic needles placed, as seen in Fig. 168. He pointed out the fact that the force in question must be a circulating one, since, otherwise, it would be impossible to explain why it acts in contrary directions on opposite sides of the circuit. He compared this action with that which a current of water would exert if circulating in a ring-shaped canal. It was this analogy that led to the name electric current being applied to the force which comes from the entire battery circuit. Ampère proposed the rule to which we have already referred, as conceiving a

Origin of the term electric current.

person to be swimming in this current, which would, consequently, enter at his feet and pass out at his head. He did this in order to determine the direction in which the needle would be deflected by the current.

Ampère's experiments with movable electric circuits.

After having studied carefully the manner in which a fixed conductor, carrying an electric current, acts on a movable magnetic needle, Ampère next turned his attention to a fixed magnet, and pointed out that it exerted a similar action on a

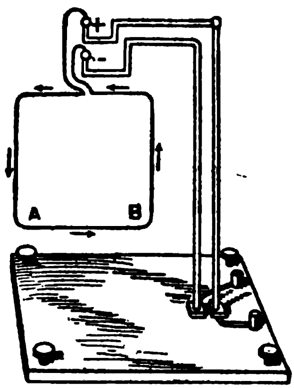


FIG. 169.—One form of Ampère's movable active conductors for showing action of magnets, as of movable circuits on each other.

movable conductor through which a current of electricity is flowing. He formed a movable circuit by bending a copper wire in the shape of a rectangular circuit, A B, Fig. 169, and suspended the same by placing the ends of this circuit in small cups, + and —, filled with mercury, in the manner shown. On passing a current from a voltaic battery through this movable circuit he found that it tended to set itself at right angles to a bar magnet placed below it, parallel to A B, the direction in which the current

was flowing through the nearest part of the movable conductor.

Ampère also showed that active movable conductors; *i.e.*, movable conductors through which electric currents are passing, attracted or repelled other active movable conductors, according to the direction in which the currents flowed through both conductors. He thus opened up a new branch of electricity, called electro-dynamics, or that branch of electric science which treats of the force which one electric current exerts on another. He showed that these actions are entirely magnetic, and are due to the

Ampere's discoveries in electro-dynamics.

FIG. 170.—De la Rive's Floating Active Coil for electro-dynamic experiments. Note the direction of the current produced by the floating voltaic couple of zinc Z and carbon C, as indicated by the curved arrows.

circular magnetic fields produced around active conductors. During these investigations, Ampère discovered the following laws; viz., Electric currents that are flowing in the same direction attract one another. Electric currents flowing in opposite directions repel one another. Two electric currents crossing at an angle attract each other when both currents flow toward or from the point of crossing, and repel each other when one flows toward and the other from such point of crossing. The force with which these attractions and repulsions take place is directly proportional to the strength

Laws of electro-dynamics.

of the current passing, multiplied by the length of the conductors through which they are passing, and is inversely proportional to the distance between them.

De la Rive's floating active coil.

A very simple form of movable active conductor was devised by De la Rive. This consists, as shown in Fig. 170, of a single voltaic cell, the circuit of which is connected with a small coil of insulated wire, and the two properly balanced, and supported on a cork, are made to float in a vessel containing dilute sulphuric acid. The approach of the pole of a magnet will cause either attraction or repulsion, according to the name of the magnetic pole, as well as the direction in which the current is flowing through the floating coil.

Ampère's theory of magnetism.

After having studied the effects produced by the mutual action of electric currents on each other, Ampère proposed an ingenious theory concerning the nature of magnetism. In this theory he attributes the cause of all magnetism in steel, or other permanent magnets, to the action of electric currents. After having carefully ascertained the various actions which a current exerts on different parts of a movable magnet, he saw that these actions could all be explained by regarding each small part of the magnet as being replaced by a closed electric current flowing around it in a plane at right angles to its length.

All magnets probably contain minute electric circuits in the ultimate particles.

After having ascertained, in this manner, the direction such currents must have at different parts of the magnet, in order to produce the results which were actually caused by the active conductor, he came to the conclusion that the peculiar properties of any magnet should be produced by numerous electric currents flowing in the same direction through minute circuits, all of which were situated

in planes parallel to one another, and perpendicular to the axis of the magnet.

Ampère assumed that the ultimate particles of all magnetizable substances have electric currents naturally circulating around them in closed circuits; that in an unmagnetized bar these currents, being undirected, all neutralize one another, and produce no effects outside the magnet; that the act of magnetization of a bar consists in causing these currents to flow in one and the same direction, the bar becoming magnetically saturated when all the separate circuits have been caused to flow parallel to

Explanation of Ampère's theory of magnetism.

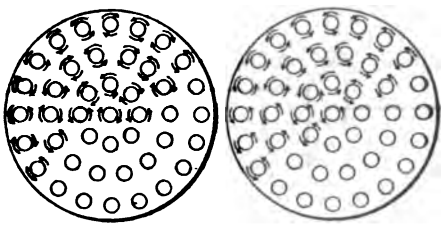


FIG. 171.—Conventionalized representation of an unmagnetized and a magnetized bar of steel, according to Ampère's theory of magnetism.

one another. The difference in both a magnetized and an unmagnetized bar is shown in Fig. 171. On the left-hand side of this figure the circuits are represented in the case of an unmagnetized bar where the separate circuits are undirected, and, therefore, have the effect of neutralizing one another. On the right-hand side of the figure, which represents a magnetized bar, they are all similarly directed. The very fact, however, that all such circuits are parallel to one another, and all flow in the same direction, will necessitate, as a careful inspection of the figure will show, that all these separate circuits except those on the extreme outside of the bar, flow in opposite directions in those parts of

the separate circuits that are contiguous to one another, and that, therefore, these parts will neutralize one another. There will, therefore, remain only the current on the outside of the bar, which must, consequently, be regarded as the magnetizing current. In other words, taking the case of a permanent steel bar magnet of rectangular cross-section, the effect of the currents produced as a result of the neutralization of all the separate circuits, except those on the outside, will be to produce single electric currents, which may be represented by nu-

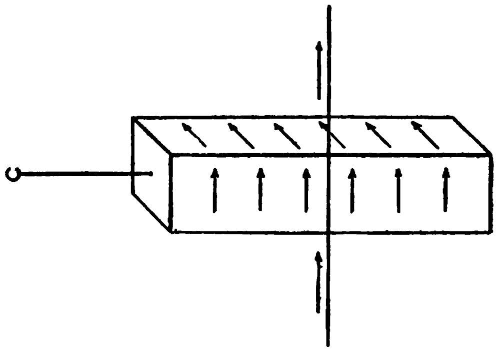


FIG. 172.—Ampère's conventionalized representation of effect of electric single and separate currents in producing the magnetism in a magnet.

merous closed circuits, parallel to one another, and at right angles to the length of the bar, as shown in Fig. 172, where, in order to avoid complexity, only a few of the many circuits are represented.

Objection to Ampère's theory by reason of the conservation of energy.

It has been objected to Ampère's theory that, according to the doctrine of the conservation of energy, it is exceedingly improbable that an electric current could possibly flow continuously in a circuit without the expenditure of energy. Ampère's theory has, therefore, been generally rejected by most scientific men, who have proposed some of the theories

already referred to under the general head of magnetism. It will be noticed that Ampère's theory bears a close resemblance to many of these other theories, in that, like some of them, it regards the ultimate particles of matter as naturally magnetic. It goes further, however, than these theories in assuming a fairly reasonable cause for the presence of magnetization.

Prof. Oliver Lodge dissents from the objection urged by many scientific men against Ampère's theory, remarking in this connection: "To all intents and purposes, certainly atoms are infinitely elastic, and why should they not also be infinitely conducting? Why should the dissipation of energy occur in respect to an electric current circulating wholly inside an atom? There is no reason why it should."

Oliver Lodge on Ampère's theory of magnetism.

Governed entirely by theoretical considerations, Ampère endeavored to construct a magnet artificially, by means of electric currents flowing through conductors or wires arranged so as to produce the results which he claimed existed in all natural magnets. After repeated failures he at last produced a coil of wire which he called a solenoid. Such an active coil is the equivalent of the magnetizing current, which he assumed, by his theory, actually existed.

Ampère's solenoidal coil.

Strictly speaking, the solenoid, as required by Ampère's theory, would consist of a very great number of minute circular circuits all parallel to one another, and with all their faces of like polarity turned in the same direction, each circuit being independent of all the other circuits. The solenoid which Ampère produced consisted of an insulated wire wrapped in the form of a helix or spiral, *ab*,

Fig. 173. Such a conductor, if suspended at *m, m,* by *p, p,* as shown, will, when traversed by an electric current, come to rest like a magnetic needle, with its north end pointing, approximately, to the earth's geographical north pole. It will, under these conditions, be attracted or repelled by the approach of a magnet pole, *b,* the result being dependent on the

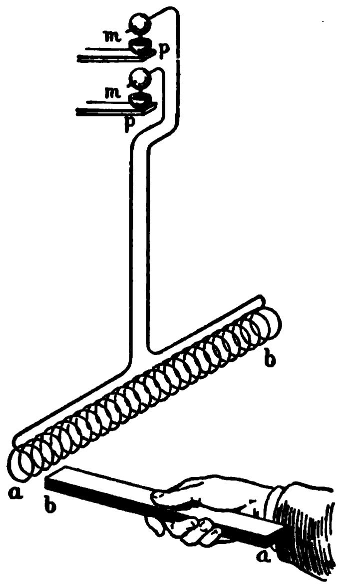


FIG. 173.—Ampère's Practical Solenoid.

name of the pole that is approached to it, as well as on the direction in which the current is circulating through its coils.

Attractions and repulsions produced by solenoids.

Solenoids, when traversed by the electric current, possess all the properties of magnets. In the solenoids shown in Fig. 174, all the phenomena of magnetic attraction and repulsion can be obtained by the approach of a solenoidal coil held in the hand

of the experimenter to the poles or faces of another solenoidal coil, suspended as shown in the figure.

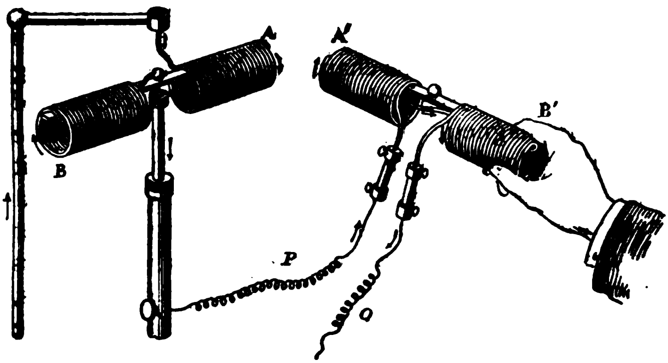


FIG. 174.—Two separate solenoidal coils for showing mutual attractions and repulsions. Note that when the solenoid A' B', held in the hand, is approached to the solenoid A B, supported as shown so as to be free to move, the electric currents in the approached ends are flowing in opposite directions, and that therefore repulsion occurs; or, in other words, like magnet poles repel each other.

In any solenoid the polarity of the resulting magnetism depends on the direction of the magnetic flux produced by its coils. Now, remembering that this **Polarity of active conducting loop.**

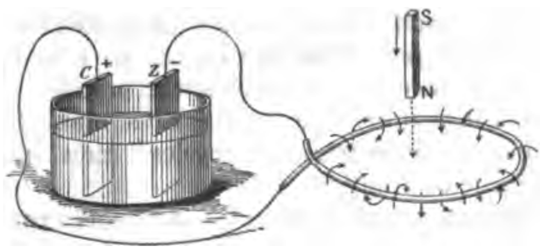


FIG. 175.—Magnetic Flux produced by the current from a single voltaic cell passing through a single conducting active loop. Note that the upper face of such a loop will possess south magnetic polarity, and will therefore attract the pole N of the bar magnet S N and tend to draw or suck it into the loop.

flux circulates around an active conductor in planes at right angles to the length of the conductor, it will be readily understood that by bending the conductor into the shape of a loop, as shown in Fig. 175, all

such circular flux will enter the loop at one of its faces and will pass out at the other face. Moreover, by changing the direction of the current through the active conductor, the face at which the flux enters and leaves will also be changed. Now, remembering the convention regarding the assumed direction of lines of magnetic flux, it is evident that the face of such a loop at which the magnetic flux leaves it will possess north magnetic polarity, and the face at which it enters it south magnetic polarity. In other words, a single active conducting loop will possess north polarity at all portions of one of its faces, and south polarity at all portions of its opposite face. The condition of affairs that would exist in this case is exactly similar to that which would exist were an extended plate of steel, or magnetizable substance, so magnetized that all parts of one of its sides or surfaces possess north polarity and its opposite side or surface south polarity. Such a plate would possess what is sometimes called a lamellar distribution of magnetism.

Lamellar distribution of magnetism.

The great value of Ampère's work in this field is generally recognized by scientific men, who have honored his memory by naming the practical unit of electrical quantity, the ampère, after him. Silliman, in his "Principles of Physics," thus speaks of the value of Ampère's work:

The practical unit of current, the ampère, named after the distinguished French physicist.

"Immediately after the first announcement of Oersted's discovery of the magnetic powers of a conjunctive wire, Ampère, one of the most renowned of the French physicists (born 1755—died 1836), commenced a series of experiments (September, 1820) to determine the laws concerned in these curious phenomena. Of three principal hypotheses which he framed to this end, he finally accepted and demonstrated the following, viz.:

"A magnet is composed of independent elements or molecules, which act as if a closed electric circuit existed within each of them: in other words, each of these magnetic molecules may be replaced by a conjunctive wire bent on itself, in which a constant current of electricity is maintained, as from a Voltaic circuit.

Silliman on Ampère's discoveries.

"This hypothesis he maintained by singularly ingenious experiments, many of which were the direct suggestion of the hypothesis itself, and he brought all, by his power of mathematical analysis, into exact conformity with his theory. This theory recognizes only such forces as are common to mechanical physics, and often called 'push and pull' forces. These forces are mutual, and belong to all electric currents. In permanent magnets, the minute circular and parallel currents, pertaining, by this theory, to each magnet molecule, all act at right angles to the magnetic axis or line of force. Hence, as in Oersted's experiment, the magnetic needle strives to place itself at right angles to the path of the current on the conjunctive wire, it follows, that currents in the magnet seek a parallelism to that in the conjunctive wire. Granting this to be true, it follows, as a corollary from the premises—

"1st. That two free conducting wires must attract or repel each other, according to the direction of the currents in them.

"2d. That a conjunctive wire may be made in all respects to simulate a magnet."

CHAPTER XXIX

THE ELECTRO-MAGNET

"For this invention [that of the electro-magnet] we may rightfully claim the very highest place. Electrical engineering, the latest and most vigorous offshoot of applied science, embraces many branches. The dynamo for generating electric currents, the motor for transforming their energy back into work, the arc lamp, the electric bell, the telephone, the recent electro-magnetic machinery for coal-mining, for the separation of ore, and many other electro-mechanical contrivances, come within the purview of the electrical engineer. In every one of these, and in many more of the useful applications of electricity, the central organ is an electro-magnet."—*The Electro-Magnet:* S. P. THOMPSON

Independent discovery by Davy and Arago of ability of active copper conductor to attract iron filings.

WE have already referred to the fact, in the quotation from the paper read by Davy, before the Royal Society of London, announcing Oersted's discovery, that a copper wire through which an electric current is passing, acquires magnetic properties, as is evidenced by its power of attracting iron filings. This same fact was independently discovered by Arago, almost immediately after the announcement by Oersted of his discovery. Arago noticed that a short conductor of any metal attracted iron filings while an electric current was passing through it. Arago also made numerous experiments in magnetizing steel needles by the electric current and found that in order to obtain the best results it was necessary to bend the conductor into the form of a hollow coil or helix, and place the needle inside the coil. He showed that the discharge from a Leyden-jar battery also magnetized

steel bars. Arago announced these discoveries to the Royal Academy of Sciences, on September 25, 1820, and thus antedated Davy, who made his announcement to the Royal Society of London in the paper before referred to, on the 16th of November, 1820.

Arago the first to announce his discovery.

Where a bar of steel is placed inside a magnetizing coil, and the discharge of a Leyden jar passed through the coil, a peculiar condition exists in the distribution of the resulting magnetism. Instead of the needle being magnetized, as in the case of a current from a voltaic battery, with the same polarity from the surface to the centre of the bar, it is found that there are alternate layers of opposite magnetism. This may be shown either by grinding off the successive layers, or by dissolving them away with acids, when successive alternate polarities will be observed. This character of magnetization was formerly called anomalous magnetization. In 1842, Henry discovered the true character of such magnetization, and showed that there is nothing anomalous about it whatever, the peculiar distribution depending on the fact that, in the case of the Leyden-jar discharge, the current rapidly changes its direction. He remarks on this subject as follows:

Explanation of so-called anomalous magnetization.

"This anomaly, which has remained so long unexplained, and which, at first sight, appears at variance with all our theoretical ideas of the connection between electricity and magnetism, was, after considerable study, satisfactorily referred to an action of the discharge of a Leyden jar which had never before been recognized. The discharge, whatever may be its nature, is not correctly represented (employing the simplicity of Franklin) by the single transfer of an imponderable fluid from one side of the jar to the other; the phenomena require us to admit the existence of a principal discharge in one direction

Henry on anomalous magnetization.

and then several reflex actions backward and forward, each more feeble than the preceding, until the equilibrium is obtained. All the facts are shown to be in accordance with the hypothesis, and a ready explanation is afforded by it of a number of phenomena which are to be found in the older works on electricity, but which have until this time remained unexplained."

Arago's experiments on the magnetization of steel needles by active coils.

There was no readily obtained cotton-covered or silk-covered insulated wire in the times of Arago, so that he was obliged to ensure insulation by wrapping his conducting wire around the outside of a glass tube, inside of which he placed the steel bars that were to be magnetized. In the course of his experiments on the magnetization of steel needles, Arago wrapped a long helix around a glass tube; but, instead of continuing the direction of the winding throughout its entire length, he changed this direction, and found, on placing a long steel needle inside the tube, that, besides the usual poles at the extremities of the steel bar there were produced intermediate poles at all points where the direction of the winding was changed. In other words, he obtained anomalous magnets. In this way Arago showed that the polarity of the magnetism produced by magnetizing coils depends on the direction in which the magnetizing current passes through the coils, since any change in the direction of winding, would, of course, change the direction in which the magnetizing current would flow.

Anomalous magnets obtained by active coils or helices.

The polarity of a helix or coil can be deduced from the direction in which the electric current is passing through it. Helices or coils are said to be right-handed, or left-handed, according to the direction in which they are wound. A right-handed helix is

one that is wound in a right-handed direction, that is, in a clockwise direction. A left-handed helix is one that is wound in a left-handed direction, or counter-clockwise. In Fig. 176 are shown three differently wound helices. That shown at 1, at the top of the figure, is a right-handed helix. That shown at 2, in the middle of the figure, is a left-handed helix. That shown at 3, at the bottom of the

Right and left-handed coils or solenoids.

Consequent magnetic poles.

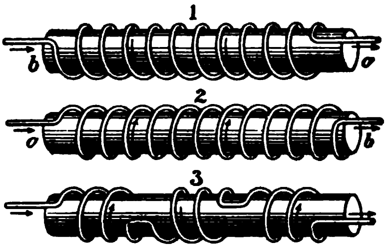


FIG. 176.—Variously Wound Helices. Note how the change in the direction of winding at 3 causes a change in the direction of the current.

figure, is wound so as to produce an anomalous magnet with more than two poles. These intermediate poles are sometimes called consequent poles.

Turning now back to Fig. 160, which shows the direction of the circular lines of magnetic force produced by a current flowing through a conducting wire, and bearing in mind that when an active conductor is bent into the form of a loop, these lines of force pass into the loop at one face, and pass out of it at the opposite face, as shown in Fig. 175, it will be easy to understand the differences in the magnetic polarity produced when an electric current passes through the differently wound helices or coils shown in Fig. 176.

Polarity of helices determined by the direction in which the magnetic flux enters or leaves them.

In order, however, to make this easier, reference may be had to Fig. 177, where the direction of wind-

Magnetic polarities produced by different windings.

ing is, perhaps, more readily understood. Here the polarity of the electro-magnet is indicated by the letters N and S, and the direction of the current re-

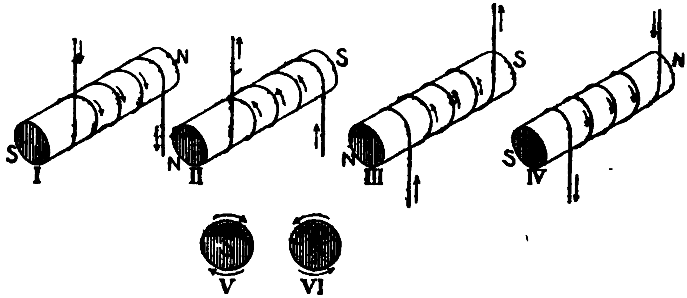


FIG. 177.—The character of the magnetic polarity produced by electric currents flowing through coils wound in right and left-handed directions.

quired to produce these poles is shown at the bottom of the figure.

Mnemonic for determining magnetic polarity.

Different plans have been suggested in order to fix in the mind the direction of the current required to produce north and south polarities. A very simple

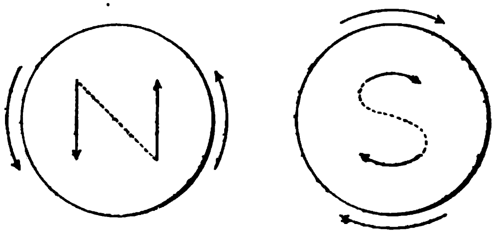


FIG. 178.—Simple method for remembering magnetic polarity produced by differently directed electric currents.

rule is indicated in Fig. 178, where the direction of the currents required to produce north and south poles can be remembered from the direction of the arrows at the points of beginning and ending of the capital letters N and S. Here it will be seen that, in order to produce north magnetic polarity

the current must circulate counter-clockwise, while to produce south magnetic polarity it must circulate clockwise.

Scientific discoveries in electro-magnetism naturally followed one another very rapidly on the announcement of Oersted's great discovery, so that 1820 was a memorable year in this branch of electric science. We have already mentioned some of these discoveries, such as that of Ampère, which laid the foundation of a new branch of electric science, *i.e.*, electro-dynamics, as well as his splendid researches in electro-magnetism. **Why 1820 was a memorable year in electric science.**

A discovery, however, of perhaps even greater importance than either of these, is yet to be recorded. We refer to the apparently exceedingly simple discovery made by Sturgeon, in 1825, that soft iron remains magnetic only while under the influence of the magnetizing force, and that it loses its magnetism as soon as it is removed from the influence of this force. But what was far more important, Sturgeon immediately made a practical application of his discovery by inserting a bar of soft iron inside the hollow coil or helix, through which an electric current was passing. He found that, under such circumstances, the strength of the magnetism produced by the coil was increased in an astonishing degree. **Great discovery of Sturgeon in 1825.**

The magnets produced by Sturgeon differed from those produced by Ampère and others, in that cores of soft iron were placed inside the magnetizing coils. In this way the strength of the magnetism produced by a given current was much greater when the core was present than when it was absent. Moreover, such a magnet possessed the valuable property of immediately acquiring its magnetism as **Nature of Sturgeon's invention.**

soon as the current passed through the coils, and of immediately losing it as soon as such current ceased to pass. Sturgeon proposed the name of electro-magnet for such forms of magnet, in order to distinguish them from permanent steel magnets. The term electro-magnet, in this sense, is still employed in electric science.

Sturgeon thus describes, in curious language for a scientific man, his electro-magnet of 1825:

Sturgeon's electro-magnet of 1825.

"When first I showed that the magnetic energies of a galvanic conducting wire are more conspicuously exhibited by exercising them on soft iron than on hard steel, my experiments were limited to small masses—generally to a few inches of rod iron about half an inch in diameter. Some of these pieces were employed while straight, and others were bent into the form of a horseshoe magnet, each piece being compassed by a spiral conductor of copper wire. The magnetic energies developed by these simple arrangements are of a very distinguished and exalted character, as is conspicuously manifested by the suspension of a considerable weight at the poles during the period of excitation by the electric influence.

"An unparalleled transiliency of magnetic action is also displayed in soft iron by an instantaneous transition from a state of total inactivity to that of vigorous polarity, and also by a simultaneous reciprocity of polarity in the extremes of the bar—versatilities in this branch of physics for the display of which soft iron is pre-eminently qualified, and which, by the agency of electricity, become demonstrable with the celerity of thought, and illustrated by experiments the most splendid in magnetics. It is, moreover, abundantly manifested by ample experiments, that galvanic electricity exercises

ELECTRICITY IN THE COMPOSING ROOM

The Mergenthaler typesetting machine, or Linotype, run by an electric motor. This machine increased the production of the hand compositor six or eight times, and so made possible the huge modern newspaper. The electric motor is seen back of the machine

a superlative degree of excitation on the latent magnetism of soft iron, and calls for its recondite powers with astonishing promptitude, to an intensity of action far surpassing anything which can be accomplished by any known application of the most vigorous permanent magnet, or by any other mode of experimenting hitherto discovered. It has been observed, however, by experimenting on different pieces selected from various sources, that, notwithstanding the greatest care be observed in preparing them of a uniform figure and dimensions, there

Sturgeon's description of his magnet.

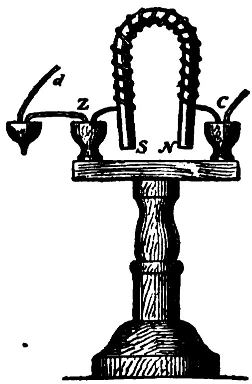


FIG. 179.—Sturgeon's Electro-Magnet. Note the fact that this magnet differed from those produced by Ampere, solely in being provided with a core of soft iron.

appears a considerable difference in the susceptibility which they individually possess of developing the magnet powers, much of which depends upon the manner of treatment at the forge, as well as upon the natural character of the iron itself.

"The superlative intensity of electro-magnets, and the facility and promptitude with which their energies can be brought into play, are qualifications admirably adapted for their introduction into a variety of arrangements in which powerful magnets

so essentially operate and perform a distinguished part in the production of electro-magnetic rotations; while the versatilities of polarity of which they are susceptible are eminently calculated to give a pleasing diversity in the exhibition of that highly interesting class of phenomena, and lead to the production of others inimitable by any other means."

The form taken by the first electro-magnet is shown in Fig. 179. This, it will be observed, is the exact form that the ordinary horseshoe magnet takes to-day. There is only a single turn of wire wrapped on the bent iron core. Z and C represent wooden cups, partly filled with mercury, for the purpose of readily establishing connection between the voltaic battery and the magnetizing coils of wire.

Important role played by electro-magnets in the electric arts and sciences.

It is somewhat difficult thoroughly to realize the important part that the electro-magnet plays in the electrical arts and sciences of to-day. The peculiar value of the electro-magnet lies in the ease with which it acquires and loses its magnetism, when the magnetizing current is either started or stopped. It is, indeed, a fortunate circumstance that the magnetic memory of soft iron for its past magnetic condition is so extremely poor, while, at the same time, its readiness to again take on a magnetic condition is so marked. It is these properties that have rendered the electro-magnetic telegraph a possibility, and have permitted the electro-magnet to be utilized in various electro-magnetic signalling apparatus, annunciators, burglar alarms, dynamo-electric machines, electric motors, and, in fact, in all the other devices in which electro-magnets form an essential part of the working apparatus. Indeed, were the electro-magnet removed from all electric apparatus to-day, without the possibility of being replaced by some other means, it

would occasion a loss to the practical arts and sciences that would be difficult to estimate.

A great improvement in the electro-magnet, as made by Sturgeon, was introduced by Prof. Joseph Henry, about 1830. This consisted in employing a great length of very fine wire wound in a great number of turns around the bar to be magnetized. Magnets so constructed possess the valuable property of readily working at the far end of a long conducting line. Henry's electro-magnets were constructed by him for use in his great invention of the electro-magnetic telegraph. These magnets were capable of readily responding to the movements of a telegraphic key at the distant end of the line, and rapidly opened and closed the magnetizing circuit, since they almost instantly acquired magnetic properties on the closing of the circuit, and almost instantly lost them on the opening of the same.

Henry's improvements in electro-magnets.

In his improved magnets, it will be seen that Henry combined the principle of the Schweigger multiplier with the soft-iron core of Sturgeon. He thus describes his invention of the high-resistance electro-magnet in Volume 19 of Silliman's "American Journal of Science and Arts," of January, 1831:

Henry's use of Schweigger's principle.

"In a paper published in the Transactions of the Albany Institute, June, 1828, I described some modifications of apparatus, intended to supply this deficiency of Mr. Sturgeon, by introducing the spiral coil on the principle of the galvanic multiplier of Prof. Schweigger, and this I think is applicable in every case where strong magnets can not be used. The coil is formed by covering copper wire, from $\frac{1}{40}$ to $\frac{1}{25}$ of an inch in diameter, with silk; and in every case, which will permit, instead of using a single conducting wire, the effect is multiplied by introduc-

Henry's description of his electro-magnets.

ing a coil of this wire, closely turned upon itself. This will be readily understood by an example: thus, in the experiment of Ampère, to show the action of terrestrial magnetism on a galvanic current, instead of using a short single wire suspended on steel points; sixty feet of wire, covered with silk, are coiled so as to form a ring of about twenty inches in diameter, the several strands of which are bound together by wrapping a narrow silk ribbon around them. The copper and zinc of a pair of small galvanic plates are attached to the ends of the coil, and the whole suspended by a silk fibre, with the galvanic element hanging in a tumbler of diluted acid. After a few oscillations, the apparatus never fails to place itself at right angles to the magnetic meridian. This article is nothing more than a modification of De la Rive's ring on a larger scale.

Henry's modification of De la Rive's floating ring.

"Shortly after the publication mentioned, several other applications of the coil, besides those described in that paper, were made in order to increase the size of electro-magnetic apparatus, and to diminish the necessary galvanic power. The most interesting of these was its application to a development of magnetism in soft iron, much more extensively than to my knowledge has been previously effected by a small galvanic element.

"A round piece of iron, about one-quarter of an inch in diameter, was bent into the usual form of a horseshoe, and instead of loosely coiling around it a few feet of wire, as is usually described, it was tightly wound with thirty-five feet of wire, covered with silk, so as to form about four hundred turns; a pair of small galvanic plates, which could be dipped into a tumbler of diluted acid, was soldered to the ends of the wire, and the whole mounted on a stand. With these small plates, the horseshoe became much

Henry's device to obtain powerful electro-magnets.

more powerfully magnetic than another of the same size, and wound in the usual manner, by the application of a battery composed of twenty-eight plates of copper and zinc, each eight inches square. Another convenient form of this apparatus was contrived, by winding a straight bar of iron nine inches long with thirty-five feet of wire, and supporting it horizontally on a small cup of copper containing a cylinder of zinc; when this cup, which served the double purpose of a stand and the galvanic element, was filled with the dilute acid, the bar became a portable electro-magnetic magnet. These articles were exhibited to the Institute in March, 1829.

Henry's portable electro-magnet.

"The idea afterward occurred to me, that a sufficient quantity of galvanism was furnished by the two small plates, to develop, by means of a coil, a much greater magnetic power in a larger piece of iron. To test this, a cylindrical bar of iron, one-half an inch in diameter, and about ten inches long, was bent into the form of a horseshoe, and wound with thirty feet of wire; with a pair of plates containing only two and one-half square inches of zinc, it lifted fourteen pounds avoirdupois. At the same time, a very material improvement in the formation of the coil suggested itself to me, on reading a more detailed account of Prof. Schweigger's galvanometer, and which was also tested with complete success upon the same horseshoe; it consisted in using several strands of wire, each covered with silk, instead of one;—agreeably to this construction, a second wire, of the same length as the first, was wound over it, and the ends soldered to the zinc and copper in such a manner that the galvanic current might circulate in the same direction in both, or, in other words, that the two wires might act as one; the effect by this addition was doubled, as the horseshoe,

Powerful electro-magnets from weak galvanic batteries.

with the same plates before used, now supported twenty-eight pounds."

Henry thus describes some of his experiments in the direction of employing separate coils of magnetizing wire:

"To test these principles on a larger scale the experimental magnet was constructed, which is shown in Fig. 6 [our Fig. 180]. In this a number of compound helices were placed on the same bar, their ends left projecting, and so numbered that they

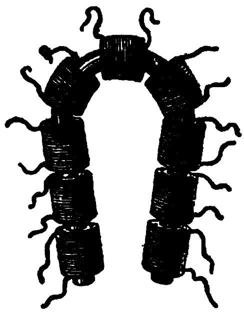


FIG. 180.—Henry's Early Form of Horseshoe Electro-Magnet, with separately wound magnetizing coils. These separate coils were variously connected, according to the character of voltaic battery employed to supply the magnetizing current.

could all be united into one long helix, or variously combined in sets of lesser length.

"From a series of experiments with this and other magnets, it was proved that in order to produce the greatest amount of magnetism from a battery of a single cup a number of helices is required; but when a compound battery is used then one long wire must be employed, making many turns around the iron, the length of wire, and consequently the number of turns, being commensurate with the projectile power of the battery.

"In describing the results of my experiments,

the terms 'intensity' and 'quantity' magnets were introduced to avoid circumlocution, and were intended to be used merely in a technical sense. By the intensity magnet I designated a piece of soft iron, so surrounded with wire that its magnetic power could be called into operation by an intensity battery; and by a quantity magnet, a piece of iron so surrounded by a number of separate coils that its magnetism could be fully developed by a quantity battery.

"I was the first to point out this connection of the two kinds of the battery with the two forms of the magnet, in my paper, in Silliman's Journal, January, 1831, and clearly to state that when magnetism was to be developed by means of a compound battery one long coil must be employed, and when the maximum effect was to be produced by a single battery a number of single strands should be used. . . . Neither the electro-magnet of Sturgeon nor any electro-magnet ever made previous to my investigations was applicable to transmitting power to a distance."

Varieties of magnetic circuits.

The complete path of magnetic flux when it leaves a magnet at its north pole, and again enters it at its south pole, after having traversed the region outside the magnet, is called, as we have already stated, a magnetic circuit. A magnetic circuit can be divided conveniently into two parts; viz., that which is found in the region outside the magnet, and that which exists inside the magnet. In any magnetic circuit the magnetic flux may complete its path through a circuit entirely of iron, through a circuit partly of iron and partly of air, or through a circuit entirely of air. There thus arise three kinds of magnetic circuits; viz., the ferric magnetic circuit, where the flux passes entirely through iron; the æro-ferric circuit, where the flux passes partly through air and partly through iron; and the non-ferric circuit,

Ferric, æro-ferric, and non-ferric magnetic circuits.

where the flux passes entirely through air. In the electric circuit, as we have already seen, the strength of the electric current, as determined by means of Ohm's law, is directly proportional to the electromotive force acting on the circuit to produce a flow of electricity, and inversely proportional to the electric resistance that opposes such flow. In a similar manner, in the magnetic circuit the strength of the magnetic flux that passes is proportional to the magneto-motive force, or the force that causes the flow of magnetism, and inversely proportional to the magnetic resistance of the circuit, or, as it is generally called, to the magnetic reluctance. The practical unit of magnetic flux is called the weber. The practical unit of magnetic reluctance is called the oersted, after the discoverer of electro-magnetism; and the practical unit of the magneto-motive force is called the gilbert, after Dr. Gilbert, the early writer on magnetism. Just as in the electric circuit,

Application of Ohm's law to the magnetic circuit.

$$\text{ampères} = \frac{\text{volts}}{\text{ohms}}$$

so in the magnetic circuit,

$$\text{webers} = \frac{\text{gilberts}}{\text{oersteds}}$$

Definitions of the Weber, Oersted, and the Gilbert.

From the above the definitions of the practical magnetic units can be readily understood; viz., the weber is equal to the amount of magnetic flux that is produced in a circuit by a magneto-motive force of one gilbert acting through a magnetic reluctance of one oersted; the gilbert is the magneto-motive force that will cause a magnetic flux of one weber to pass through a magnetic circuit against a reluctance of one oersted; while the oersted is the reluctance which will limit the passage of magnetic flux through a circuit to one weber when under a magneto-motive force of one gilbert.

Since it is the electric current, *i.e.*, the ampères, or the coulombs-per-second, that produces magnetic flux, we can express the M. M. F. in any circuit by the current strength that passes through the magnetizing coils. If, for example, in a coil of a given number of turns, a current strength of say one ampère produces a certain amount of magnetic flux; then, if this current strength be doubled, the amount of magnetic flux produced will likewise be doubled. In the same way, if the number of turns on the magnetizing coil be increased, the amount of magnetic flux will be correspondingly increased. For example, if a coil with say five hundred turns, produces a certain flux, a similarly wound coil containing one thousand turns will produce twice this amount, provided, of course, the magnetizing current passing through it remains the same. An ampère-turn, that is, a single conducting loop through which one ampère of current is passing, can, therefore, be taken as a unit of magneto-motive force. An ampère-turn is greater than a gilbert, being equal to about 1.25 gilberts.

The ampere-turn as a unit of magneto-motive force.

Let us now inquire into the reasons for the great increase in the strength of magnetism produced, by a given magnetizing current traversing a magnetizing coil, by the simple introduction of a bar of soft iron within the coil. Here the magnetizing current is the same, and the number of ampère-turns is the same. The only difference is that a mass of soft iron is placed inside the magnetizing coil. Since the strength of the magnetism has increased, the amount of the magnetic flux must have been increased. The question, then, arises where the extra magnetic flux comes from. Take, for example, any non-ferric magnetic circuit, such as that of the practical solenoid, shown in Fig. 173. How can we ex-

How a soft iron core placed in a magnetic circuit increases the amount of its flux.

plain the very great increase in the magnetism that has resulted by the simple introduction of a bar of soft iron within the solenoid?

Residual magnetism. It was, at first, believed by some that the increase in the amount of magnetic flux that immediately passed through the circuit when the iron was introduced, was due to a decrease in the magnetic reluctance of the circuit. This decrease arose, it was urged, from the fact that that part of the magnetic circuit within the coil was then occupied by the core of soft iron, which possessed a much greater magnetic permeability, or, in other words, a much smaller magnetic reluctance; and that this decrease necessarily caused an increase in the amount of magnetic flux. It was, however, soon pointed out, that, in the case of a ferric magnetic circuit, such as would be produced in a closed iron ring, around which was wrapped a magnetizing coil, such circuit did not lose its magnetism on the opening of the circuit, but that a great proportion of the flux remained in the condition which is known as residual magnetism.

Prime and aligned molecular magnetic flux. For this reason it is now generally believed that the increased magnetic flux is due to the molecular magnets naturally present in the iron, as has already been referred to in several of the theories of magnetism; that the magnetizing current causes all these molecular magnets to become aligned and to point in one and the same direction, so that there is added to the flux produced by the magnetizing current, and sometimes called the prime flux, a still greater quantity of aligned or structural molecular flux, which depends for its amount both on the character of the iron itself, and on the intensity of the magnetizing flux. This explanation thus shows in a satisfactory manner the cause of the increase in the magnetic

effects produced by the introduction of a soft iron core into an active solenoid.

Various forms are given to electro-magnets. One of the simplest of these consists of a straight bar of soft iron introduced within the magnetizing coil. Here the direction of the polarity will depend both on the direction of winding and on the direction in which the current passes. Generally, however, it is preferable to bring the two poles of the electro-magnet nearer together, thus producing a magnet of

Straight-core electro-magnet.

Simple horseshoe magnet.

Fig. 181.—Simple Horseshoe Electro-Magnet. Note here that the magnetizing coils on the separate legs are wound in the same direction, just as if they had been wound on a straight bar and the bar afterward bent in the shape of a horseshoe.

a horseshoe type, as shown in Fig. 181. In such cases it is not convenient to cover the entire bar with the magnetizing coils. It is easier to make them in two separate coils, placing one coil on each leg of the magnet, as shown.

Where two separate magnetizing coils are used care must be taken to so connect the ends of the coils as to cause the current passing through them to flow in the same direction, as is seen in Fig. 182, where the magnetizing coils *a* and *b* are connected as if

Two magnetizing coils connected so as to act as a single coil wound in the same direction.

they were wound in the same direction. This is necessary, so that a single north pole only is produced at *a*, and a single south pole at *b*, and a neutral point at *c*.

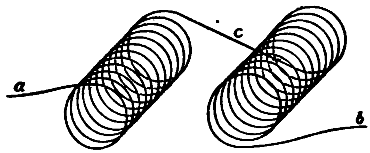


FIG. 182.—Connection of the separate magnetizing coils, so as to enable them to act as a single coil wound in the same direction.

Reluctance of horseshoe magnet smaller than that of straight-bar magnet.

Since the resistance offered by air to the passage of magnetic flux is far greater than the resistance offered by iron, the reluctance of a horseshoe

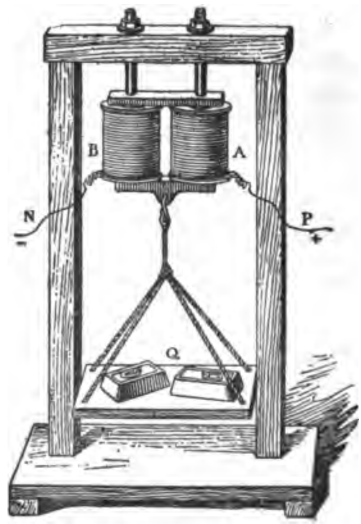


FIG. 183.—Horseshoe Magnet, formed by union of two separate straight-bar magnets. Note that the separate iron cores are connected by a thick plate of soft iron, placed in good contact with the cores; the magnetizing coils are connected with the electric source at P and N.

magnet is necessarily less than that of a straight bar magnet. Consequently, the amount of magnetic

flux will be greater, and, necessarily, the strength of its magnetism greater.

Electro-magnets, produced as above described, may be of great strength. In the electro-magnet shown in Fig. 183, the magnet is suitably supported on a wooden frame, and provided with a bar of soft iron called the armature, placed between its poles at A and B. The object of the armature is not difficult to understand. Before it is placed on the magnet poles a part of the magnetic circuit is formed by air, or the magnetic circuit is of the aero-ferric type. As soon, however, as the armature is placed on the magnet poles, the entire magnetic circuit

Electro-magnet formed by union of the separate straight-bar electro-magnets.

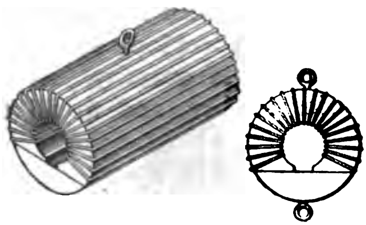


FIG. 184.—Joule's Cylindrical Horseshoe Magnet. Note here the great extent of polar surfaces exposed to the opposing surface of the armature.

is completed through iron; hence, the reluctance of the circuit is decreased, and the strength of the flux is correspondingly increased. At the same time, the structural magnetic flux of the armature is added to the magnetic flux of the magnet, thus still further increasing the strength. This latter is, in all probability, one of the principal causes.

Sometimes the horseshoe type of magnet takes a cylindrical shape, as shown in Fig. 184. This particular form of electro-magnet was devised by Joule, who thus describes the construction of his cylindrical electro-magnet in a paper published in August, 1840, in the "Annals of Electricity":

Joule's cylindrical horseshoe magnet.

"I proceed now to describe my electro-magnets, which I constructed of very different sizes in order to develop any curious circumstance which might present itself. A piece of cylindrical wrought-iron, eight inches long, had a hole one inch in diameter bored the whole length of its axis, one side was planed until the hole was exposed sufficiently to separate the thus formed poles one-third of an inch. Another piece of iron, also eight inches long, was then planed, and, being secured with its face in contact with the other planed surface, the whole was turned into a cylinder eight inches long, three and three-quarter inches in exterior, and one inch in interior diameter. The larger piece was then covered with calico and wound with four copper wires, covered with silk, each 23 feet long and one-eleventh of an inch in diameter—a quantity just sufficient to hide the exterior surface, and to fill the interior opened hole."

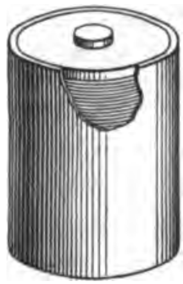


Fig. 185.—Ironclad Electro-Magnet. Note that the soft-iron cylinder surrounding the magnetizing coils changes the straight-bar electro-magnet into a horseshoe magnet.

Ironclad magnet. Still another modification of the horseshoe magnet is shown in Fig. 185. Here the core of the magnet takes the shape of a single straight bar. In order, however, to bring the opposite poles close together, and thus decrease the magnetic reluctivity of the circuit, as well as to add structural magnetic

flux to it, one of the poles is connected with a casing of soft iron placed outside the magnetizing coils, and extending near the extremity of the other pole, thus bringing the two poles nearer together. This form of horseshoe magnet is sometimes called an ironclad magnet.

Two general classes of electro-magnets.

Electro-magnets may be divided into two general classes, according to the purposes for which they are intended. They may either be magnets designed mainly for the purpose of possessing a powerful attraction for their armatures at fairly considerable distances; or, they may be intended mainly to possess considerable power of drawing or holding their armatures to their poles.

Magnets that attract their armature with great force.

The attraction between a magnet and its armature depends both on the strength of the magnetic flux in its circuit, as well as on the area of the polar surfaces between which the attraction is taking place. Its greatest increase of strength for thus attracting or holding its armature will be reached when the polar surface has been increased as far as is possible without, at the same time, failing to maintain as strong a flux as is possible between the poles and the armature.

Magnets that attract their armature at fairly considerable distances.

That a magnet shall possess the power of attracting its armature at a fairly considerable distance, of course, necessitates that it shall be of the aeroferric type. For this reason, since its magnetic reluctance will be fairly great, the magneto-motive force of its magnets must be as great as possible.

Where a fairly considerable mass of iron is employed with powerful magnetizing coils, electromagnets of wonderful strength can be obtained.

Some idea of this strength may be seen from a powerful electro-magnet which was constructed at the United States Torpedo Station, at Willett's Point, Long Island Sound. Here a sixteen foot cannon, containing some 50,000 pounds of iron, was provided with a huge magnetizing coil ten miles in length. This gigantic electro-magnet had 5250 turns, so that with the magnetizing current employed, which was about twenty-one ampères, the flux that was caused to pass through this mass of iron was that produced by a magneto-motive force obtained from 110,250 ampère turns.

Powerful gun electro-magnet at the United States Torpedo Station.

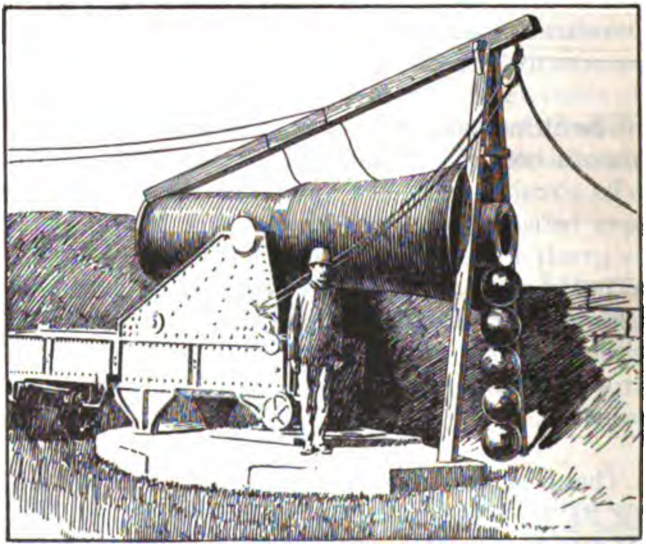


FIG. 186.—Huge Gun Electro-Magnet of U. S. Torpedo Station on Long Island Sound. Compare the size of the cannon balls pendent on the magnet pole with the soldier standing alongside the gun-magnet.

It will readily be understood that this flux, together with the aligned or structural flux, produced an exceedingly powerful electro-magnet. Even at a distance of some seventy feet from the gun, the

Great power of huge gun electro-magnet.

intensity of flux was as strong as that produced by the earth's magnetism. The general appearance of this monster electro-magnet is shown in Fig. 186. Here a number of cannon balls, each of which weighs 230 pounds, are seen suspended in a chain from one end of the gun. **Immense weight sustained.**

The ability of magnetic flux to readily pass through the human body is also well illustrated in the

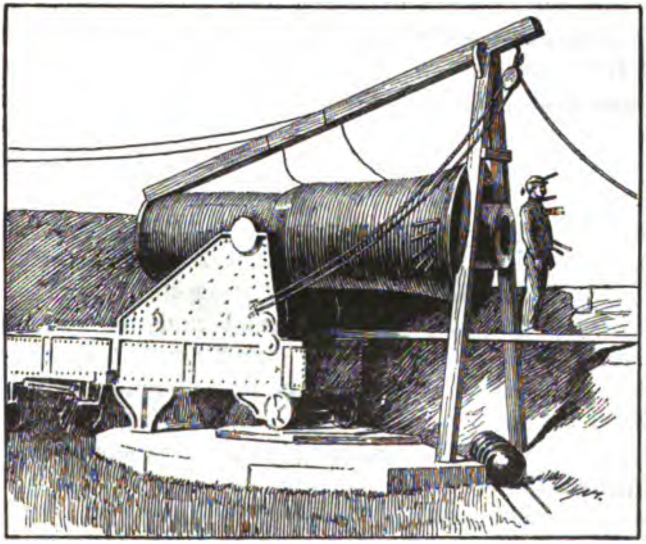


FIG. 187.—Magnetic flux from monster gun electro-magnet passing through body of soldier and attracting heavy iron spikes.

case of the above-mentioned monster gun magnet. In Fig. 187, a soldier is seen standing in front of one of the poles. The magnetic flux is passing through his body quite readily, as evidenced from the fact that heavy spikes of iron can be seen in the figure as supported on his body against the force of gravity. When an armature of soft iron was placed on the pole of the gun magnet, it required the united **Magnetic flux passing through human body.**

efforts of some sixteen strong men pulling at a rope and tackle in order to separate it from the magnet.

Silliman's description of Henry's large electro-magnet

It will be understood that, with the extremely powerful currents that can readily now be obtained from large dynamo-electric machines, the strength of the electro-magnets of to-day are necessarily far in excess of those which were produced many years ago. Nevertheless, the following description by Silliman of a powerful electro-magnet, made by Prof. Henry, for the Yale College Laboratory, in 1831, shows that extremely powerful results were obtained even in those early days:

Henry's electro-magnet in Philosophical Cabinet of Yale College.

"Prof. Henry, on a soft iron bar of fifty-nine pounds weight, used twenty-six coils of wire, thirteen on each leg, all joined to common conductors at their opposite ends, and having an aggregate length of seven hundred and twenty-eight feet. This apparatus, with a battery of four and seven-ninths feet of surface, sustained two thousand and sixty-three pounds, avoirdupois: with a little larger battery surface it sustained twenty-five hundred pounds. This electro-magnet was constructed for Yale College Laboratory, in 1831, and is still among their instruments."

Methods of magnetization of steel needles and magnetic bars, etc.

In order to produce permanent magnetization in hardened steel it is necessary that sufficiently powerful magneto-motive forces be employed to align the molecular magnets; for, as we have seen, it requires a greater force to do this in hardened steel than it does in soft iron. Various methods have been employed for this purpose. We have purposely waited before describing these methods until the principles of electro-magnetism were more clearly set forth.

Where it is desired to obtain the greatest possible

strength of magnetism in a hardened bar of steel, powerful electro-magnets are employed for magnetizing, but where uniformity in the direction of the magnetization is the principal requirement, as in the case of compass needles, permanent magnets are preferably employed.

Dr. Gowan Knight, a London physician, describes, in the Philosophical Transactions, of 1846, a method employed by him for the magnetization of compass needles. This method consisted in placing the needle to be magnetized on the upper surface of two bar magnets, so that the cup provided for suspending the compass needle came exactly midway between the two opposite magnet poles N and S, as shown in

Knight's method of magnetizing steel magnets.

FIG. 188.—Knight's Method of Magnetizing Steel Needles. Note that the two magnetizing compound magnets M and M' have their N and S poles symmetrically placed as regards the centre of the bar *s n* that is being magnetized. During this motion it is necessary to hold the magnet *n s* in place, so that the poles S and N, of the magnetizing magnets, may leave it simultaneously at its extremities.

Fig. 188. The magnetizing bars are then withdrawn in opposite directions, as indicated by the arrows. Where the needle is small, a single movement of the magnetizing bar will be sufficient, but where it is so desired, several movements may be employed.

Where stronger effects are desired, compound-bar magnets are employed in place of single-bar magnets. Two of such compound-bar magnets may be used simultaneously, as shown in Fig. 189, where the bar B B', to be magnetized, is rested on the opposite poles of two compound-bar magnets M and N, placed

Method of magnetizing bar magnets.

in the same straight line at a distance apart somewhat smaller than the length of the bar to be magnetized. Two compound-bar magnets A A′, having their opposite poles separated by a piece of wood, are inclined to the bar B B′ as shown, and are then moved successively from one end of the bar to the other, so that the number of strokes upon each half of the bar shall be the same. When the last stroke is given, the united poles are brought to the middle of the bar, and are withdrawn perpendicularly. If so desired, these movements may be repeated on the other side of the bar B B′. While this method of

Care taken in ending the stroke.

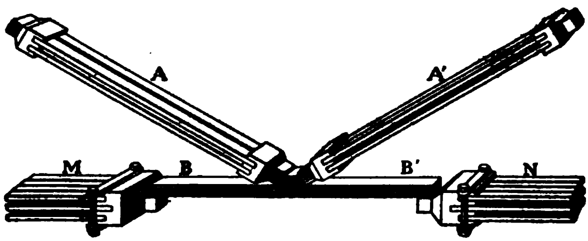


FIG. 189.—Method of Magnetizing a Bar Magnet. A simultaneous double magnetic touch of the magnets A and A′ is here employed.

magnetization produces powerful poles, it is objectionable from the fact that, unless great care be taken, the magnet will be found to possess consequent poles.

In all cases the steel is, of course, properly hardened before magnetization. Where compound magnets are employed, each bar is separately magnetized, and then placed with all the similar poles together.

How permanent magnets should be laid away.

In order to retain their magnetism, permanent magnets when not in use should be laid aside as nearly as possible in the position in which they would come to rest if free to move like a magnetic needle when under the influence of the earth's magnetism.

When placed near each other, their opposite and not their similar poles should face each other. It is better, however, always to place armatures on the magnet poles. Bar magnets can best be kept in pairs, being placed one over the other, with their opposite poles together. In other words, the magnets should be so placed that the earth's flux or the flux of neighboring magnets shall pass through them in the same direction as does their own flux.

Bar magnets are best kept in pairs.

Where electro-magnets are employed for magnetization, their poles may be directly applied to the bars to be magnetized. Sometimes, however, a hollow magnetizing coil, as shown in Fig. 190, has a

FIG. 190.—Use of Hollow Magnetizing Coil for Magnetizing Steel Bars.

strong magnetizing current sent through it. The bar to be magnetized is then introduced into the hollow coil, and moved in opposite directions, until it is sufficiently magnetized. Here, however, care must be taken not to remove the magnet from the coil while the current is turned on, but to stop its motion at the central portion of the coil, and then open the magnetizing circuit, when it can be safely withdrawn, otherwise the magnetism produced will be unevenly distributed.

Use of magnetizing active coil or spiral for magnetization of steel magnets.

When it is desired to produce some particular effect in any part of a magnetic circuit by the action of the magnetic flux, as, for example, to have the poles of a magnet attract an armature placed near

Useless or leakage magnetic flux.

them, it is, of course, necessary that as nearly as possible, all the flux passing through the circuit shall pass between the magnet poles and the surface of the armature. If any of the flux passes elsewhere outside the magnet, it will be useless for the purposes of drawing or attracting the armature. It may, therefore, be called useless or stray magnetic flux, or, as it is sometimes called, leakage flux, or simply magnetic leakage. For example, in the lines of magnetic flux shown in the case of the permanent horseshoe magnet, in Fig. 91, leakage flux can be seen passing between the sides of the horseshoe magnet, above the poles as well as at the poles. All that flux which fails to pass through the armature is useless for all purposes of acting on the armature.

Non polarized and polarized armatures.

We have already referred to an armature of soft iron as being placed across the poles of an electro-magnet. Sometimes, however, the armature, instead of being thus made of soft iron, is formed from a permanent magnet of hardened steel. Such an armature is said to be polarized, in order to distinguish it from an ordinary or non-polarized armature of soft iron. When an armature of soft iron is employed, it will be attracted or drawn toward the magnet poles, no matter whether such poles possess north or south polarity; but where such an armature is polarized, the passage of the electric current through the magnetizing coils of the electro-magnet will cause the armature either to be attracted or repelled, according to the direction in which the current is passing through the magnetizing coils. Such armatures are employed, as we shall see, in a variety of electro-telegraphic apparatus.

The polarized armature is generally placed between the poles of an electro-magnet, instead of

being placed, like the ordinary soft iron armature, over both poles. Consequently, the movement of the polarized armature toward the north or the south pole of an electro-magnet, between whose poles it is placed, will depend upon the direction of the current through the magnetizing coils of such electro-magnet. In other words, a change in the direction of the current through the magnetizing coils will produce a change in the pole toward which the polarized armature will be attracted.

Difference in the position of non-polarized and polarized armatures.

When the magnetizing coil or solenoid is provided with a movable core of soft iron, the device is called

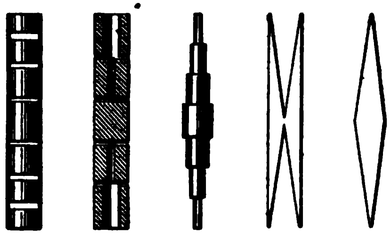


FIG. 191.—Krizik's Cores for Sucking Magnets. Note that in all these various shapes the greatest mass of the soft iron is situated near the middle of the cores.

a solenoidal core. Such a device is also sometimes called a sucking magnet. Its core differs from the immovable core of an electro-magnet. If this movable core consists of a bar of uniform diameter, when it is placed inside the solenoid coil the attraction or pull will not be of the same strength throughout all parts of the solenoid. It is greatest when the bar is just entering the solenoid. As soon as it passes the middle of the coil the pull decreases; and when the centres of the bar and the coil coincide all motion ceases, since both ends of the solenoid attract the movable core in opposite directions. In order to obtain as nearly a uniform pull as possible through-

Solenoidal core or sucking magnet.

Krizik's cores for solenoids.

out all parts of the solenoid, soft iron cores are employed, of such shapes as will ensure a greater mass of metal near the middle of the bar. Such cores or bars are called Krizik's cores. They may assume a great variety of shapes as will be seen in Fig. 191.

ELECTRICITY IN THE STEEL PLANT—CHARGING-MACHINE

The old way, and the new, of filling an open-hearth steel-making furnace with the materials to be melted. The electrical charging-machine, the "Wellman," requires but one man

V

ELECTRO-DYNAMIC INDUCTION, OR THE PRODUCTION OF ELECTRICITY FROM MAGNETISM

CHAPTER XXX

FARADAY AND HIS RESEARCHES ON THE PRODUCTION OF ELECTRICITY FROM MAGNETISM

"Take him for all in all, I think it will be conceded that Michael Faraday is the greatest experimental philosopher the world has ever seen."—PROFESSOR JOHN TYNDALL

WITH the single exception of Oersted's great discovery of the production of magnetism from electricity there has, probably, never been a single discovery in electricity and magnetism that has produced so great an effect on the electric arts and sciences, and has proved of such far-reaching value to the world, as the discovery of the production of electricity from magnetism, made on the 29th of August, 1831, by Michael Faraday. This discovery gave to the electric arts the dynamo-electric machine, the induction coil, the electric motor, and the alternating-current transformer. The extended use of all these types of electric apparatus shows how great was the value of Faraday's discovery. No wonder, therefore, that it immortalized the man who made it. Faraday's discovery should indeed be ranked, in importance, before the discovery of Oersted, were it not, in point of fact, dependent on Oersted's discovery.

Faraday's great discovery of August 29, 1831.

Early belief in connection between electricity and magnetism.

Faraday was by no means the first who believed that it should be possible to obtain electricity from magnetism. Many before him had endeavored to do so, but it was reserved to Faraday, after persistent and continued efforts, finally to solve this great problem.

Basis for Faraday's belief.

Faraday's reasons for believing that electricity should be produced from magnetism were generally as follows: If a wire carrying an electric current acts like a magnet, as Oersted had shown, then such a wire should be able to produce electric currents in conductors placed near it. Moreover, since electric currents produce magnetism, so magnetism, on its part, should be able to produce electric currents.

Reason for failure of Faraday's first experiments.

Faraday's first experiments were made with electric currents. It is a curious circumstance that in these early investigations Faraday made a mistake of the same character as that made by the many investigators who preceded Oersted in attempts to obtain magnetism directly from the voltaic battery. They failed because their experiments were made with batteries on open circuit. Faraday, at first, signally failed to obtain any electrical currents in conductors placed near other conductors through which electric currents were passing; or, as we shall hereafter call them for convenience, active conductors, because he did not look for results until the electric currents in such active conductors had been fully established.

It is now well known that when an electric circuit is closed, some little time is required before the full current strength is established, and, in the same way, when an electric circuit is opened it requires some little time for the current strength to reach

zero. It is only while the current strength is either increasing or decreasing that the current is able to produce currents by induction in neighboring conductors. The arrangements which Faraday made in order to induce electric currents in conductors placed near active conductors, were correct save in one respect only, and this was the important one, that he did not look for the establishment of such currents until the current flowing through the active conductor had obtained its full strength. Consequently, he failed to obtain any deflection of the needle of the galvanometer connected with the neighboring circuit. He carefully repeated his experiments in various ways, undaunted by his repeated failures. Conceiving that possibly he was not operating with sufficiently powerful currents in his active conductors, he employed stronger and stronger voltaic batteries, but still with negative results. At last, however, nature did for Faraday what she always is ready to do for a patient investigator, who will intelligently inquire of her—she gave him a hint. In point of fact, she had been doing so throughout all his experiments, but this time Faraday took the hint. It came in the shape of a slight movement of the galvanometer needle, both at the moment of making or completing the circuit, and at the moment of breaking or opening it.

Why Faraday finally succeeded in producing electricity from magnetism.

With this new indication before him, Faraday repeats his experiments, and soon makes the discovery which immortalizes his memory. He observes that, during the time an electric current is varying in strength, that is, while its strength is either increasing or decreasing, it will produce by induction a flow of electricity in a neighboring conductor, and that, moreover, such induced current continues only while the current strength in the active conductor

His discovery immortalizes his memory.

is changing, that is, while it is either increasing or decreasing.

As the result of a number of careful experiments, Faraday soon ascertained that the electric current thus produced by the induction of an active circuit on a neighboring conductor, at the moment of making the circuit in the active conductor, flows in a direction opposite to that of the current in the active conductor, that the current produced on breaking the circuit flows in the same direction as that in the active conductor. He called induction produced in this way volta-electric induction.

Directions of induced electric currents.

Bearing in mind the important fact discovered in his experiments on the induction of electric currents in neighboring conductors, that it was only in electric circuits, the strength of whose currents was either increasing or decreasing, Faraday soon succeeded in obtaining electricity direct from magnets. He did this both by moving coils of insulated wire toward or from magnet poles, or toward or from active coils of wire. He found that the currents were induced in the coils only while the coils were moving and the magnets were fixed; while the coils were fixed and the magnets were moving; or, while both were moving toward or from each other. In all such cases, however, he found that the currents instantly ceased as soon as the motions ceased.

Electric currents obtained by the motions of magnets or active conductors.

In order to show that the electricity produced by induction from magnets or active conductors differed in no respect from electricity produced by frictional electric machines, voltaic batteries, or thermo-electric batteries, Faraday employed the electricity obtained directly from magnetism to produce

Identity of electricity from any source.

all the characteristic effects of the electricity from the before-mentioned sources. In this way he obtained disruptive sparks, magnetized steel needles, and deflected the needle of a galvanometer. At first, however, he did not succeed in obtaining chemical action by the electric current, as will be seen from a statement made by him in Volume One of his "Experimental Researches in Electricity":

"All attempts to obtain chemical effects by the induced current of electricity failed, though the precautions before described, and all others that could be thought of, were employed. Neither was any sensation on the tongue, or any convulsive effect upon the limbs of a frog, produced. Nor could charcoal or fine wire be ignited. But upon repeating the experiments more at leisure at the Royal Institution, with an armed loadstone belonging to Professor Daniell and capable of lifting about thirty pounds, a frog was very *powerfully convulsed* each time magnetic contact was made. At first the convulsions could not be obtained on breaking magnetic contact; but conceiving the deficiency of effect was because of the comparative slowness of separation, the latter act was effected by a blow, and then the frog was convulsed strongly. The more instantaneous the union or disunion is effected, the more powerful the convulsion. I thought also I could perceive the *sensation* upon the tongue and the *flash* before the eyes; but I could obtain no evidence of chemical decomposition."

Quotation from Faraday's "Experimental Researches in Electricity."

We know now, however, that when sufficiently strong or properly commuted such currents possess marked powers of both producing an electric arc between carbon rods, and causing chemical action, as the hundreds of thousands of horsepower of electric current employed every day in the different parts of

Currents produced by electrodynamic induction capable of producing chemical decomposition and forming voltaic arcs.

the world to carry on various electro-chemical processes, abundantly attest.

Simple character of apparatus employed by Faraday

Faraday employed very simple apparatus in his early experiments in this field. In some of these experiments he wrapped a coil of wire around a bar of soft iron, and, connecting the ends of this coil with the terminals of a galvanometer, as shown in Fig, 192, he observed, whenever the ends of this soft iron bar or armature were placed in contact with the poles of an electro-magnet, formed by arranging a couple of bar magnets with their opposite poles in contact, so as to produce a variety of horseshoe magnet, that the needle of the galvanometer is deflected in a certain direction; but that if the arma-

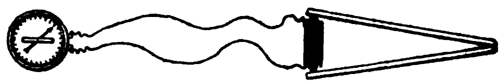


FIG. 192.—Simple apparatus employed by Faraday in the production of electricity from permanent magnets.

Magneto-electric induction.

ture remained in contact, the current soon ceased to pass, and the needle came into its position of rest as when no current was passing. As soon, however, as the armature was removed from the poles, the needle was deflected in the opposite direction,showing that a current was again passing but now in the opposite direction. Faraday called these phenomena magneto-electric induction, in order to distinguish them from induction produced by electric currents, which, as we have seen, he called volta-electric induction.

Faraday discovered that, by employing more powerful magnets, he could readily produce currents by induction in a helix by merely bringing it in the neighborhood of the magnet poles without touch-

ing them, and that the current produced by the approach of the coil toward the poles was in the opposite direction to that produced by its being moved away from such poles.

Induction currents produced by mere approach and withdrawal of magnet.

We must not fail, before concluding this extremely brief description of Faraday's researches, to call attention to the form taken by two early types of extremely important electric apparatus; viz., the dynamo-electric machine and the induction coil,

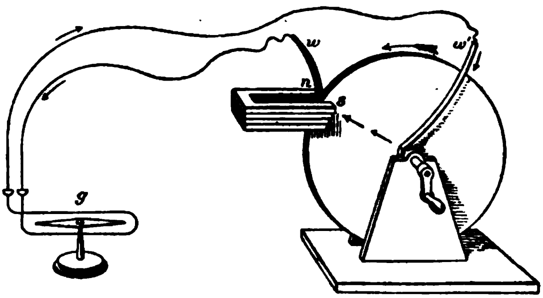


FIG. 193.—Faraday's Disk Dynamo, the first dynamo-electric machine ever built. Note that as the copper plate or disk is rotated in the direction of the large arrow, between the poles *n* and *s*, currents are produced in the direction of the small arrows. These currents are taken from the copper disk by the contacts or brushes *w* and *w'*.

or the alternating-current transformer. His baby dynamo, the very first dynamo the world ever saw, resulted from his investigations in the production of electricity from permanent magnets. It consisted, as shown in Fig. 193, of a copper plate, so mounted on an axis as to be capable of rotation, between the poles of a powerful compound-bar magnet, so as to cut its lines of force. A galvanometer, *g*, was connected by means of conducting wires with the rotating disk. One of these wires was provided with a spring contact, which pressed against the axis of the disk, and the other with a similar spring

Faraday's baby dynamo.

contact, which pressed against the circumference of the disk. Under these circumstances, when the disk was rapidly rotated, the electro-motive forces produced in it caused a current to flow from the axis of the disk toward its circumference, and, hence, to be carried off by the conducting wires connected with the terminals of the galvanometer. In this way, Faraday converted the mechanical energy required to rotate the disk into electric energy. By reversing the direction of rotation of the disk, the direction of the current produced was also changed, such current now flowing from the circumference toward the axis of the disk.

Method employed for carrying off currents produced in rotating disk.

This early type of dynamo was the forerunner of the great machines which have done so much for the production of cheap and powerful electric currents. It was an extremely inefficient machine, and no little trouble was experienced in obtaining good contacts for carrying off the currents produced, owing to the difficulty of keeping the springs in firm contact with the circumference and axis of the disk. Faraday afterward produced dynamo machines in which coils of wire were so rotated before magnet poles as to cut the lines of magnetic force, as is done in the dynamos of to-day.

Troubles caused by spring contacts.

The early form given to the induction coil or alternating-current transformer is shown in Fig. 194. Here the coils of wire A and B were wrapped, as shown, on opposite halves of a soft iron ring. One of the coils A was connected with a voltaic battery, and the other B with a galvanometer. It was found that, whenever the current began to flow in the coil A, a current was produced in the coil B, as indicated by the deflection of the needle in a given direction; and, whenever the circuit was broken

through the coil A, a current was also produced in B, but in the opposite direction, as shown by the de-

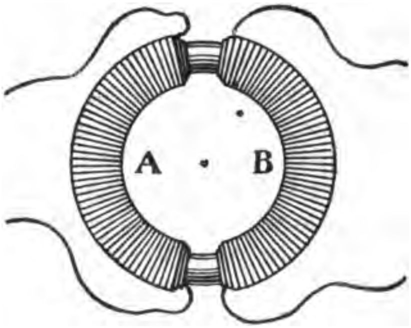


FIG. 194.—Faraday's Iron Ring for showing Voltaic Current Induction. This was the First Alternating-Current Transformer ever constructed.

flection of the galvanometer needle. This apparatus was the first transformer or induction coil ever produced. In another form of early transformer, shown

Early form of first induction coil

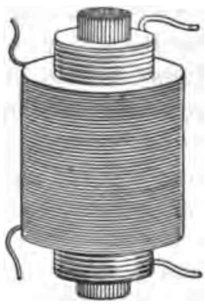


FIG. 195.—A form of early Transformer. This is sometimes called an open-circuit transformer, because its magnetic circuit is partly completed through air.

in Fig. 195, Faraday wrapped the two coils of wire, one over the other, around a bar of soft iron, in place of the iron ring shown in the preceding figure.

The name of transformer is now given to this ap-

paratus because, by its means, it is possible to alter or transform the electro-motive forces, and, consequently, the current produced by any electro-motive force that is rapidly changing its value. Calling the coil A, Fig. 194, through which the inducing current flows, the primary coil, and the coil B, in which the current is produced by induction, the secondary coil, then the electro-motive forces set up by induction in the secondary coil will compare with the value of the electro-motive forces in the primary coil, very nearly in the proportion of the relative number of turns of wire on each coil. If, for example, the primary coil be provided with fifty turns of wire, and the secondary coil with five hundred turns of wire, then the electro-motive forces in the secondary coil will be very nearly ten times as great as the electro-motive forces in the primary coil. If, however, the primary coil have the greater number of turns, then there will be a corresponding decrease in the electro-motive force of the secondary coil. It is for these reasons that transformers are divided into two different classes called respectively step-up and step-down transformers. In the former, the electro-motive forces of the primary coil are increased in the currents induced in the secondary, while in the latter they are decreased.

Origin of the name transformer

Step-up and step-down transformers.

It is not difficult to understand why the introduction of a core of soft iron into a coil of wire, in which electro-dynamic induction is taking place, should increase so markedly the amount of the induction. A core of soft iron, from its greater magnetic permeability than the air which it replaces, offers a far better path through which the lines of magnetic force can complete their circuit. Consequently, a greater amount of the flux passes

through the core, and thus decreases the amount of useless or leakage flux. But there is another and far more important reason for this increase in the intensity of the induction. With the introduction of the soft iron core into a magnetic circuit there is added, to the amount of magnetic flux produced by the magnetizing current, a still greater amount of aligned or structural flux, derived from the iron core when all its molecular magnetic circuits are aligned, so as to be able to add their flux to the prime flux of the magnetizing circuit. The considerable increase in the amount of magnetic flux thus introduced into the circuit will account for the greater part of the increased amount of electro-dynamic induction.

Why an iron core increases the inductive effects of active coils.

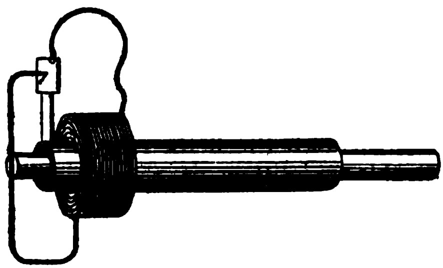


FIG. 196.—Apparatus employed by Faraday for obtaining electric spark by inductive effects of permanent magnet.

In his experiments on magneto-electric induction, Faraday succeeded in obtaining a disruptive spark discharge from a permanent magnet. He did this by placing a coil of insulated wire around a magnet near one of its poles, and, arranging its terminals as shown in Fig. 196, he succeeded, by driving the magnet rapidly through the core by means of a blow from a hammer, in inducing electro-motive forces in the coil, which set up a current that discharged itself in a disruptive spark. Faraday thus describes

Disruptive electric spark obtained by magneto-electric induction.

this experiment in the second volume of his "Experimental Researches":

Faraday on magneto-electric spark apparatus.

"About twenty feet of silked copper wire were made into a short ring helix, on one end of a paste-board tube, through which a cylindrical magnet an inch in diameter, could move freely; one end of the helix wire was fastened to a small amalgamated copper plate, and the other end bent round so as to touch this plate perpendicularly upon its flat surface, and also in such a manner that when the magnet was passed through the cylinder it should come against this wire, and separate the end from contact with the plate. The consequence was that whenever this action was quickly performed, the magneto-electric spark appeared at the place of disjunction.

How the rapid opening of the circuit was obtained.

"My apparatus was placed horizontally, and a short loose plug of wood was put into the end of the cylinder, so that the disjunction at the plate should take place at the moment the end of the magnet was passing through the helix ring, that being the most favorable condition of the apparatus. The magnet was driven with a sharp quick motion through the cylinder, its impetus being overcome, as soon as the spark was obtained, by an obstacle placed at a proper distance on the outside of a movable wire. From the brightness and appearance of the spark, I have no doubt that if both ends of a horse-shoe magnet were employed, and a jogging motion were communicated to the light frame carrying the helices, a spark equal, if not superior, to those which down to this time have been obtained with magnets of a certain power, would be produced."

We have thus, necessarily, from want of space, given an extremely brief description of Faraday's exceedingly valuable work in this department of

science. In addition to his researches in electro-dynamic induction, he made numerous experimental investigations in other branches of electricity and magnetism. These researches are recorded in three magnificent volumes, termed "Faraday's Experimental Researches in Electricity," volumes that will well repay careful study on the part of the student.

Extent of Faraday's experimental investigations

Without stopping any further to trace Faraday's investigations in the production of electricity from magnetism, we will proceed to inquire, from the standpoint of to-day, just what it was that Faraday was doing in his experiments; how the movements of conductors toward or from magnets, or the movements of magnets toward or from conductors, could produce electric currents; why electric currents were produced only during the motion of the magnet or conductor, or at the moment the current in the active conductor was either increasing or decreasing in strength.

Explanation of Faraday's work in the light of to-day.

As we all know, the passage of an electric current through a conductor produces circular lines of magnetic force encircling the conductor. It would appear to follow, therefore, that anything which would set up such circular lines of magnetic force around a conductor should produce an electric current in such conductor. Now this is what Faraday did. He discovered the conditions under which such magnetic whirls are set up around conductors. He showed that this could be accomplished by the movement of coils of wire either toward or from magnets. Expressed in a few words, Faraday's great discovery consisted in the fact that, in order to set up such magnetic whirls, and thereby produce electric currents, magnetic flux must be caused to cut or pass through conductors; or, what is the same thing,

Concise statement of nature of Faraday's great discovery.

that conductors must be made to cut or pass through magnetic flux. Just how these magnetic whirls are set up, or why they should be set up, the world is as ignorant of to-day as it was in the time of Faraday. What we do know is, that whenever magnetic flux, no matter from what source it is produced, passes through conductors, such conductors have circular magnetic flux produced around them, and, consequently, electric currents flowing through them.

E.M.F.'s produced by electro-dynamic induction.

The production of electric currents by the passage of magnetic flux through conductors is generally called electro-dynamic induction. Here, as in the case of the production of electricity by any of the different electric sources already described, what is in reality produced is not electricity directly, but electro-motive forces, that tend to set the electricity in motion. This is also the case with electro-dynamic induction. By its action electro-motive forces are set up, and these, in turn, produce an electric current in any circuit on which they are permitted to act.

How rapidly varying strength of current in active coil can cause its magnetic flux to pass through neighboring conductors.

It is easy to see how, when the magnetic flux of a permanent or an electro-magnet is employed to produce electro-dynamic induction, that either the magnet or the conductor can be moved, so as to cause the magnetic flux to pass through the conductor. At first sight, however, it is not so easy to understand how this cutting of the conductor by lines of magnetic force is brought about in the case of a conductor placed near another conductor, through which a current, whose strength is rapidly varying, is passing. The following consideration, however, will remove this difficulty. When an electric current is passing through any conductor, the lines of

magnetic force which it produces surround such conductor. As the current strength gradually increases from nothing up to its full value, the lines of magnetic force increase in number, and move outward or away from the axis of the conductor. While the current strength in the circuit is decreasing, the number of the circular lines of magnetic force decrease, and the flux contracts, or moves inward toward the axis of the conductor. Now these lines of expanding or contracting magnetic force will necessarily cut or pass through any conductor placed in their neighborhood, and this cutting will necessarily set up electro-motive forces, and, consequently, currents in the conductor.

Faraday's rank as an experimental philosopher is recognized generally all over the world. In his case, unlike those of many of the world's greatest discoverers, his ability was generally recognized by his contemporaries. As early as 1824, he was elected one of the Fellows of the Royal Society of England and was made a member of the Royal Institution in 1825. His membership in foreign learned societies increased so rapidly that, in 1844, he was a member of no less than seventy such societies.

Faraday recognized by his contemporaries

CHAPTER XXXI

VARIETIES OF ELECTRO-DYNAMIC INDUCTION

"Any displacement of the relative positions of a closed circuit, and of a current or magnet, develops an induced current, the direction of which is such as would tend to oppose the motion."—LENZ'S LAW

Varieties of electro-dynamic induction.

THERE are, generally, four different ways in which a conductor may be moved across magnetic flux, or magnetic flux moved across a conductor, so as to set up electro-motive forces, and, consequently, currents therein.

Dynamo-electric induction.

In the first place, a conductor may be moved across the flux produced by a magnet, so that it passes through or cuts such flux. The conductor, therefore, has an electro-motive force and current set up in it. Induction produced in this way is called dynamo-electric induction.

Magneto-electric induction.

In the second place, magnetic flux may be moved across a conductor by the motion of the magnet, or by the motion of an active electric circuit, so that the flux of the magnet or of the circuit may cut the conductor, and thus set up electro-motive forces and current therein. Induction produced in this way is called magneto-electric induction.

Mutual induction.

In the third place, the expanding and contracting lines of magnetic force that are set up around the axis of a conductor when the current passing through

it is rapidly increasing or decreasing in intensity, may be caused to cut or pass through a neighboring conductor. In this manner electro-motive forces and, consequently, currents, are set up in the conductor. Induction produced in this way is called mutual induction, from the fact that each circuit tends to induce electro-motive forces in the other.

Self-induction.

In the fourth place, the expanding or contracting lines of magnetic force set up around a conductor, the strength of the current passing through which is undergoing rapid variations, may cut different parts of the conductor itself, and so tend to set up electro-motive forces and currents therein. Induction produced in this way is called self-induction, or inductance.

Different ways in which the value of the induced E.M.F.'s can be increased.

The value of the electro-motive forces produced by electro-dynamic induction depends upon the rate at which the lines of magnetic force pass through or cut the conductor. In other words, the strength of the induced E.M.F.'s depends on the number of lines of magnetic force that so pass through or cut the conductor in a given time, say a second. Anything that causes an increase in the number of such lines that thus cut the conductor will increase the value of the electro-motive forces induced. It will be evident that such increase can be obtained by increasing the strength or density of the magnetic field. It can also be obtained by increasing the speed with which the wire or magnet is moved, as well as by increasing the length of the wire or conductor that is exposed to the cutting.

Since, in all practical cases of electro-dynamic induction, the wire is made in the form of conducting loops, another way of determining the value of the

Value of E.M.F.'s dependent on quantity of magnetic flux passing through conducting loops.

electro-motive forces produced is to determine the quantity or amount of flux with which such conducting loops are filled or emptied in a given time during the motion. Looked at in this light, all devices for producing electro-dynamic induction consist, practically, of means for alternately filling and emptying conducting loops with magnetic flux; the greater the number of such loops, the greater the

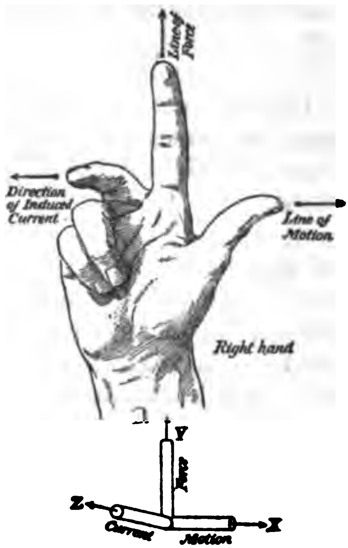


FIG. 197.—Fleming's Hand Rule for remembering the direction of the E.M.F.'s induced in conductors.

density of the magnetic flux that can be utilized for their alternate filling and emptying, and the greater the speed with which such filling and emptying is carried on, the greater the value of the electro-motive forces produced.

Let us now consider the directions of the E.M.F.'s produced by electro-dynamic induction from the

standpoint of the cutting of magnetic flux. This direction is, perhaps, best remembered by means of a rule called Fleming's hand rule. Suppose the right hand be held in the position shown in Fig. 197. Then, if a conductor be moved, in the same direction as that in which the thumb points, at right angles across the magnetic flux, which is assumed to be passing in the direction indicated by that in which the forefinger points, the E.M.F.'s generated will have a direction the same as that in which the middle finger points.

Fleming's hand rule for determining direction of E.M.F.'s induced.

A simple modification of Fleming's hand rule, which will, perhaps, make it easier to remember the

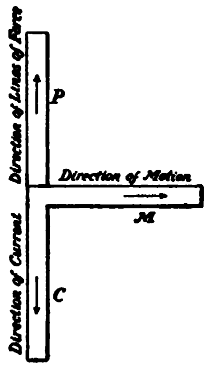


FIG. 198.—Modification of Fleming's Hand Rule.

directions of the induced E.M.F.'s consists in cutting a sheet of paper in the form shown in Fig. 198, and marking it as there indicated. If the arm P be bent upward at the dotted line, there will thus be obtained the three axes at right angles to one another, representing respectively the thumb, forefinger and middle finger of the right hand of the preceding figure. These axes may be employed in

place of the hand in the application of Fleming's rule.

We may determine the direction of the E.M.F.'s so produced from the standpoint of the filling or emptying of conducting loops with flux by the following rule; viz.:

Rule for determining direction of E.M.F.'s induced in conducting loops.

Regarding the conducting loop as the face of a watch held directly facing an observer, if the flux in filling this loop, pass through it in the same direction as does the light which passes from the watch face to the observer's eye, the induced E.M.F.'s

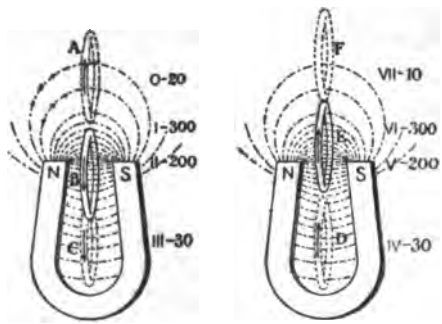


Fig. 199.—Illustration of directions of E.M.F.'s induced in conducting loop moved through field of permanent magnet.

set up around the loop will have the same direction as the hands of the watch. If, however, the flux, in filling the loop, be entering it in the opposite direction to that of the rays of light, the induced E.M.F. will have a direction opposite to that of the hands of the watch. Where the loops are emptied of magnetic flux the direction of the E.M.F.'s produced are the same as those obtained by filling the loop with flux in the opposite direction.

In order to illustrate this rule, suppose the conducting ring, Fig. 199, be held at rest in the posi-

tion A above the poles of the permanent horseshoe magnet. Then, since no change is occurring in the quantity of flux that is flowing through the loop, no change occurs in the E.M.F. But, if it be moved downward, or toward the magnet into the denser portion of the field, more flux will pour through it, and an E.M.F. will be produced whose direction, indicated by the arrows, is in accordance with the preceding rule. Moreover, the value of this E.M.F. increases until the loop reaches a position near the magnet where the amount of flux is greatest. If now the motion be continued downward, where the density of flux is less, the flux will commence to pour out of the loop, and a change will take place in the direction of the E.M.F. produced, as indicated by the arrows. If the movement of the loop now be directed upward, the E.M.F.'s produced will be those indicated by the arrows in the figure.

Directions of the E.M.F.'s induced in conducting loop during its movements through flux of magnet.

It is on the rate at which the conducting loop is being filled with and emptied of magnetic flux, and not on the amount or quantity of such flux, that the value of the E.M.F.'s produced depends. A rapid motion through a weak field will produce a higher E.M.F. than a slow motion through a dense field, provided the rate-of-change in the amount of flux that is alternately passing into and out of the loop is higher in the second case than it is in the first. For this reason, in dynamo-electric machines, any increase in the speed of rotation of the armature increases the value of the E.M.F.'s produced in it.

Value of E.M.F.'s dependent on rate of change of flux.

There is, in reality, no difference between dynamo-electric induction, where a conductor is moved across magnetic flux, and magneto-electric induction, where the flux either from a magnet or from an active conductor, is moved across another conductor.

The difference in the terms is merely for greater convenience in describing similar phenomena produced by practically the same cause; viz., the filling and emptying of conducting loops with magnetic flux. An interesting example of dynamo-electric induction, where the E.M.F.'s are produced by the movement of a conducting wire across the magnetic field of the earth itself, can be seen by means of the apparatus shown in Fig. 200. Here a coil of wire containing many separate turns is shown mounted so as to be rapidly rotated in the earth's

E.M.F.'s induced in coil by its rotation in magnetic flux of earth

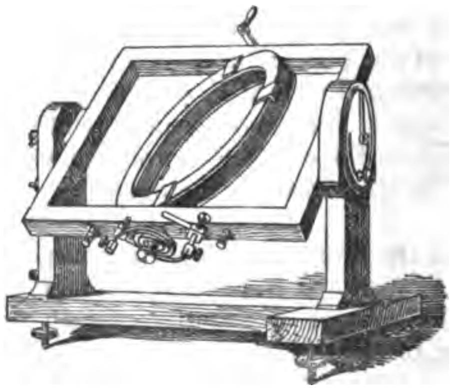


FIG. 200.—Dynamo-Electric Induction. Note that the E.M.F.'s here are produced by the magnetic flux of the earth passing into and out of the coil of wire during its rotation.

field. In this manner, being alternately filled with and emptied of the earth's flux, it has E.M.F.'s and, consequently, currents, generated in it.

Electric currents produced by motion of magnet.

Magneto-electric induction is very readily experimentally demonstrated. If, for example, the permanent steel bar magnet A B, Fig. 201, be rapidly thrust into a hollow coil of insulated wire D, the terminals of which are connected with the galvanometer G, the galvanometer needle will show the presence

of a current in D by the movement of the galvanometer needle in a certain direction. The rapid withdrawal of the magnet A B from the coil will also produce a current, but now in the opposite direction, as indicated by the movement of the needle of the galvanometer in a direction opposite to that of its first movement. In all cases these currents continue only while the magnet is moving. As soon as the magnet comes to rest, the needle of the galvanometer returns to its original position of rest, thus

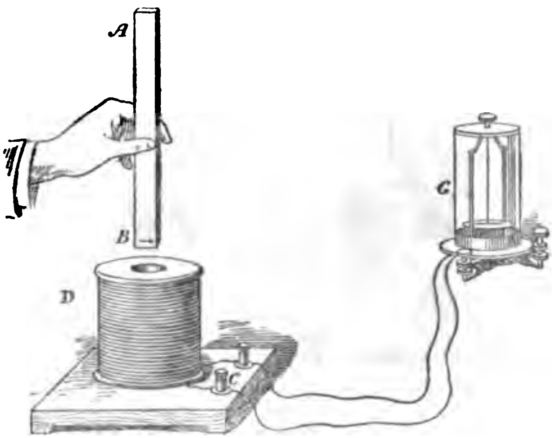


FIG. 201.—Electric current produced in coil by movement of magnet into or out of coil.

showing that no current is flowing. Moreover, the value of the E.M.F.'s produced is greater the more rapid the motions of the magnet into and out of the coil D. If these movements take place slowly, the galvanometer needle will indicate small E.M.F.'s, and, consequently, small currents by the small extent of its motion; while, if the movements take place rapidly, a greater galvanometer deflection indicates the setting up of greater currents by induction.

Effect of presence of core of soft iron in coil.

If the coil D be provided with a core consisting of a bundle of soft iron wires, shown in Fig. 202, the motion of the magnet toward and from the core will produce in E.M.F.'s and currents the same direction as were produced by its motion toward and from the hollow coil, only the value of the E.M.F.'s and currents produced will be greater, on account of the presence of the soft iron.

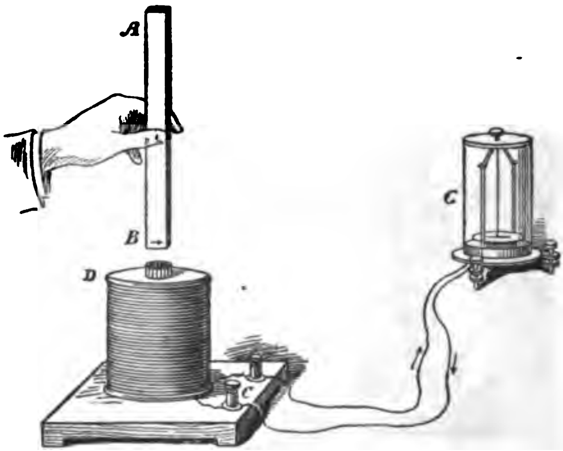


FIG. 202.—Effect of presence of soft iron core inside coil of Fig. 201.

Similar effects are produced by causing the flux of an active conductor H′ to be moved toward and from the hollow conducting coil H, Fig. 203 as were obtained by the movements of the magnet P.

Relative directions of inducing and induced currents.

Let us now consider the directions of the E.M.F.'s produced by these different means, above referred to. Calling the coil H′ through which the inducing current is passing, the primary coil, as in the case of the transforming coil shown in connection with Fig. 194, and the coil H in which the E.M.F.'s are induced, the secondary coil, then,

when the primary coil is moved toward the secondary coil, the current induced in the secondary coil is in the opposite direction to that in the primary. On the other hand, when the primary coil is moved away from the secondary coil, the current induced in the secondary is in the same direction as that in the primary. So, too, in the case of the magnet shown in Fig. 201. When this magnet is pushed into the hollow coil D, the current induced in the coil flows in the opposite direction to the direction of the electric currents that are assumed by Ampère's theory

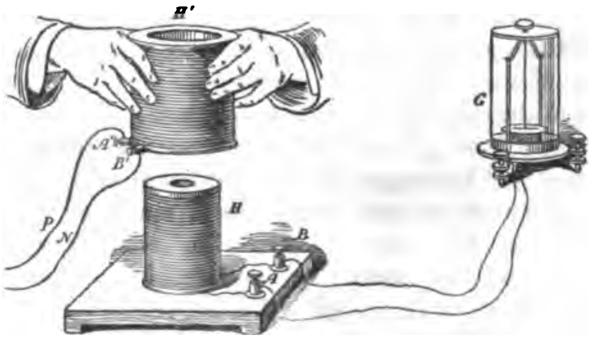


FIG. 203.—Currents induced in stationary coil by movements of active coil. Note that as the active coil H' is thrust down over the coil H, the galvanometer needle is deflected in a certain direction, and that when H' is rapidly withdrawn from H the needle is deflected in the opposite direction.

to produce such magnetism. When the magnet is drawn out from the hollow coil, the direction of the current produced in such coil is the same as that of the ampèrian currents required to produce the magnet pole.

The direction of the currents produced by dynamo-electric induction can be deduced from a consideration of the principle of the conservation of energy. This was pointed out by Lenz, and Lenz's law, general statement of.

is known in science as Lenz's law. Whenever electric energy is produced by any means, it is necessary that some other form of energy be expended. Consequently, the production of electric energy by motion either of conductors past magnets, or of magnets past conductors, calls for an expenditure of the mechanical energy required to obtain such motions. We know, from the researches of Ampère, that electric currents possess the power of attracting or repelling other electric currents, according to the direction in which such currents flow, and that magnetic flux is capable, in a similar manner, of attracting or repelling magnets, according to the directions of the magnetic flux produced by each. Now it is evident that, if we produce an electric current in the coil H of Fig. 203, by moving the coil H′ toward H, an expenditure of mechanical energy is necessary. Consequently, the direction of the current produced by such motion in H must be such as would repel the current in the coil H′, thus rendering it necessary that energy be expended in moving the coil H toward H′, despite this repulsion. But we have seen, in electro-dynamics, that parallel electric currents repel each other when flowing in opposite directions. Consequently, we would expect that the direction of the current produced in the secondary coil H, by the motion of the primary H′ toward it, should be opposite to that of the direction of the current in the primary coil, and this we find to be the case.

Application of Lenz's law to direction of currents produced by movements of active coils.

Lenz's law may, therefore, be stated as follows: The direction of the current, produced in any case of electro-dynamic induction, is such as will tend to oppose the motion by which it is caused.

Now, applying Lenz's law to the case of the cur-

rent produced by withdrawing the primary from the secondary, we would expect that the direction of the current induced in the secondary should be the same as that produced in the primary, which we find, by experiment, to be actually the case. Parallel currents flowing in the same direction attract each other, and attraction between two coils would render it necessary to expend energy in withdrawing or separating them. It is the energy thus expended which appears as electric energy in the secondary coil.

In all the different cases that we have considered of electro-dynamic induction, the E.M.F.'s are induced in the conductor only while changes are occurring in the amount of magnetic flux entering or passing out of the conducting loops. Such was the case while the conducting loop of Fig. 199 was being filled with or emptied of magnetic flux, as it was moved toward and from the poles of the permanent horseshoe magnet. Such was the case while the magnet of Figs. 201 and 202 was either approaching or moving away from the hollow conducting coil; and such was also the case while the coil of wire of Fig. 203, was moved toward or from the secondary coil.

Electric currents induced only while motion is occurring.

An actual motion of either the primary or the secondary coil, however, is not necessary in order to produce induced E.M.F.'s. In cases of mutual induction, currents are induced by means of the expanding and contracting lines of magnetic force that follow rapid variations in the strength of the current flowing through the primary coil.

Motion of expanding or contracting magnetic flux may cause induction.

Suppose, for example, that both the primary and the secondary coils be placed on the same core, by being wound one on top of the other, as shown in

Fig. 204, and that the terminals of the primary coil be connected with the terminals of the voltaic cell, and the terminals of the secondary coil be connected with the galvanometer G. Suppose, moreover, that means are provided for rapidly making and breaking the circuit of the terminals of the voltaic cell, by means of a key, or by lifting either of the terminals of the voltaic cell out of one of the mercury cups *g* or *g'*. Then, the following may be demonstrated, viz.:

Mutual induction.

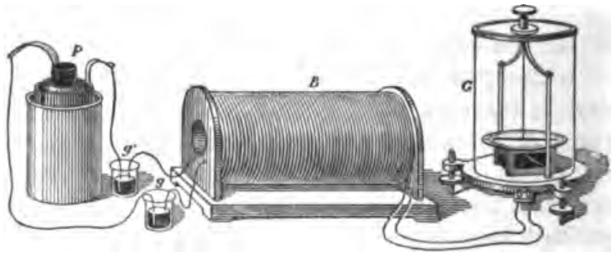


FIG. 204.—Apparatus for demonstrating mutual induction.

Directions of currents produced by mutual induction.

That at the moment of closing or making the circuit of the primary a momentary current will be induced in the secondary coil, in a direction opposite to that of the current flowing through the primary coil. This will be indicated by the movement of the galvanometer needle in a certain direction.

That, at the moment of breaking the circuit of the primary coil, a current is induced in the secondary coil that has the same direction as the current in the primary. This will be indicated by the galvanometer needle now moving in the opposite direction to that in which it moved in making the circuit through the primary coil.

As in all the other cases of electro-dynamic induction, these are but momentary currents, only flow-

Momentary character of mutually induced currents.

ing while the current in the primary coil is either increasing from nothing up to the full strength that the voltaic cell is capable of sending through the circuit, or while it is decreasing from this full strength to zero.

Induction coil or inductorium.

In the induction coil, or the inductorium, we find one of the practical applications of mutual induction. This coil forms a variety of step-up transformer, in which the secondary has a length far greater than that of the primary. Consequently, the E.M.F.'s produced by induction in the secondary may be so far increased as to be capable of causing disruptive sparks to pass through fairly considerable lengths of air. Coils of this description have been

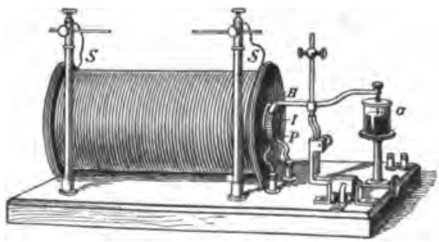


FIG. 205.—Ruhmkorff's Induction Coil or Inductorium.

devised by a number of investigators, such as by Henry, Page, Masson, Callan, Sturgeon, Ruhmkorff, and Ritchie.

Ruhmkorff induction coil.

The Ruhmkorff induction coil is shown in Fig. 205. The primary coil consists of a few turns of thick copper wire, and the secondary coil of very many turns of fine wire. The secondary turns are sometimes thousands of times greater than the number of turns in the primary, and, in the case of very large coils, may be formed from a wire several hun-

dred miles long. The primary wire is wound in the form of a hollow coil or helix. Inside of this coil is placed a soft iron core, composed of a number of separate iron wires. The primary coil is insulated from the secondary by means of a thick cylinder of glass or hard rubber. The secondary wire is wound on the outer surface of this cylinder.

Necessity for using fine wire in secondary circuit.

Owing to the great length of wire employed in such secondaries, it is necessary that very fine wire be employed, since, otherwise, the coil would become so large as to be removed too far from the influence of the expanding and contracting magnetic flux produced in the primary coil. The ends or terminals of the secondary coil are brought out at opposite ends of the coil, and are connected with the posts S and S.

Mercury break.

In order to ensure a rapid increase and decrease in the strength of the primary current, its circuit is rapidly made and broken by means of some device, in this case by means of a mercury break, shown at G.

Commutating key.

A device called a commutator, for readily changing the direction of the battery current through the primary, is shown at the nearer right-hand corner of the figure.

Current in secondary of inductorium of higher E.M.F. and smaller strength than in primary circuit.

In large induction coils, the number of turns of the secondary wire is so much greater than the number of the primary, that the voltage of a battery capable of producing only a comparatively few volts can be raised or transformed many thousands of times. Of course, it will be understood here that, since the resistance of a long, thin, primary circuit is necessarily high, the strength of the current produced in the secondary will be considerably smaller

than the strength of the current which flows through the primary.

As we have seen, the value of the E.M.F.'s, produced in any variety of electro-dynamic induction, is due to the rate at which the lines of magnetic force either cut the conductor, or pass into or out of the conducting loops. In the case of mutual induction, the value of the E.M.F.'s produced will,

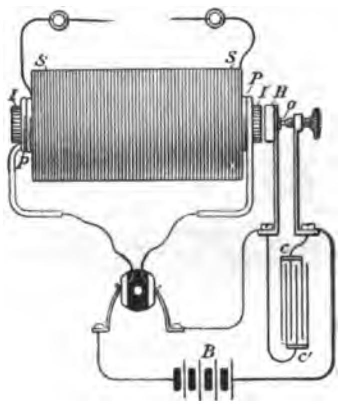


FIG. 206.—Circuit connections of induction coil showing the insertion of a condenser.

therefore, depend on the suddenness or the quickness with which the current can be both started and stopped in the primary coil. In order to decrease the length of time during which the spark produced on breaking the circuit in the primary continues, and thus increase the value of the E.M.F.'s produced in the secondary, the terminals of a condenser C, C' are introduced into the circuit of the induction coil, in the manner shown in Fig. 206. In this same figure will also be seen the various connections of the induction coil. The soft iron core

Value of E.M.F.'s in mutual induction depend on rapidity of make and break in primary coil.

is shown at I I, the primary wire is shown at P P, and the secondary wire at S S.

Construction of condenser employed in Ruhmkorff coil.

It will be seen that one of the terminals of the battery B, is connected to one terminal of the primary circuit, and that the other terminal is connected to the battery through the terminals of the condenser C, C′. The condenser consists of a number of sheets of tin-foil placed over one another, and insulated by means of sheets of paper soaked in paraffine, or by sheets of oiled silk, placed between alternate sheets of tin-foil. The tin-foil sheets project over the edge of the pile, at one side, at *s*, *s′*, *s″* and *s‴*, Fig. 207, and, at the opposite side, at *c*, *c′*, *c″* and *c‴*, so that

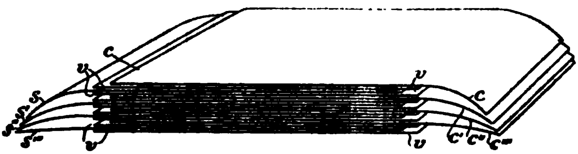


FIG. 207.—Construction of condenser employed in induction coil.

when joined by binding screws, all the odd pairs form one coating of a single condenser, and all the even pairs the opposite coating. The device shown at H O, is called an automatic circuit breaker, employed for rapidly and automatically breaking and making the circuit of the primary coil.

Action of automatic circuit breaker.

The automatic circuit breaker will be better understood from an examination of Fig. 208. Here a soft iron armature B, placed directly opposite the core of the Ruhmkorff coil, is supported by a stiff spring C, and is so introduced into the circuit of the battery, as is better shown in Fig. 206, that the circuit is closed whenever the platinum contact points on the ends of D and B touch each other.

As soon as this happens, the battery current flows through the primary circuit and makes the iron core an electro-magnet. Immediately, therefore, the armature of soft iron B is drawn or attracted toward the core of the induction coil, thus breaking the circuit of the primary. The core of the induction coil, instantly losing its magnetism, the elasticity of the spring C causes it to move back, and again closing the contact, again sends a battery current through the primary coil, and is again attracted to the iron core. In this form of interrupter the makes and

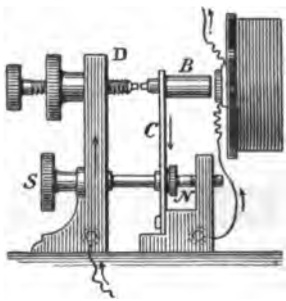


FIG. 208.—Automatic Circuit Breaker, with adjustable vibrator.

breaks of the primary circuit follow one another so rapidly as to produce a musical note.

Some Ruhmkorff induction coils have been made of great size. One, constructed by Apps, for Spottiswoode, had its secondary coil formed of two hundred and eighty miles of very thin wire. This coil gave sparks at its secondary terminals of forty-two and one-half inches in length through air, when its primary was traversed by the current from a battery of thirty ordinary Grove voltaic cells.

Large Ruhmkorff made by Apps for Spottiswoode.

Currents are induced in the secondary of induction coils both at the moment of making and break-

ing the circuit. The direct current induced on the opening of the primary circuit is of shorter duration and of higher electro-motive force than the inverse current produced at the moment of making or closing the circuit of the primary. If the secondary terminals are separated by an air space, the direct current passes in excess of the inverse current, especially if the resistance is increased by a greater length of air space between the electrodes.

Differences between the direct and the inverse sparks of induction coils.

The current from a Ruhmkorff induction coil produces a variety of effects, characteristic of high potential discharges. The physiological effects are very marked. Discharges can be obtained from large coils of sufficient strength to produce death. In smaller quantities such discharges are employed in electro-therapeutics, and, when intelligently administered, produce valuable results. The heating effects are manifested by raising to incandescence thin conductors of high resistance, placed between the electrodes.

Effects of Ruhmkorff coil discharges.

Very beautiful luminous effects are produced by the discharge of powerful induction coils, either through ordinary air, or through vacua. In moderately high vacua, vacuous spaces, such, for example, as in the egg-shaped vessel shown in Fig. 209, most beautiful luminous effects are produced by the discharges from powerful coils. If these discharges are permitted to pass while the vessels are being exhausted by means of an air pump or mercury pump, at first, when the vacuum is very low, the spark passes in the form of a slender discharge between the electrodes; when the vacuum becomes higher, a mass of light fills the vessel. This light has the color of a reddish purple. At certain pressures, especially if the vessels have been exhausted after

Luminous effects produced by Ruhmkorff coil discharges.

a small quantity of alcohol, carbon disulphide, or other substance has been introduced, the luminous discharge assumes the peculiar stratified condition shown on the right-hand side of Fig. 209, and before alluded to in connection with the dis-

Stratified luminous discharges.

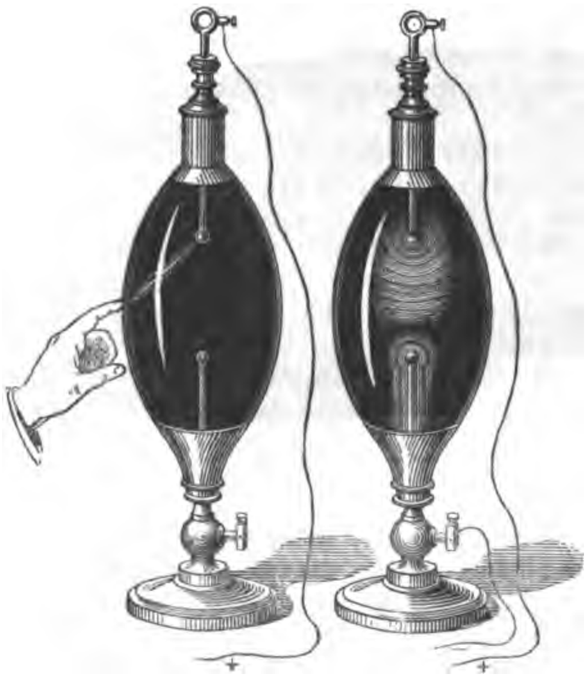


FIG. 209.—Luminous effects produced by discharges from Ruhmkorff Coils through vacuous spaces.

charge of Leyden-jar batteries. The approach of a finger of the hand to one side of the vessel while the luminous discharge is taking place, causes a remarkable deviation, as shown in the vessel on the left-hand side of the figure.

When the terminals of a large induction coil are connected with the opposite coatings of a Leyden

jar by conducting wires *i* and *d*, Fig. 210, a constant discharge by the wires *c* and *e* is obtained, the discharge taking place between *m* and *n*. Such discharges are much shorter than when the Leyden jar is not employed, but they are exceedingly brilliant, and are attended by a deafening sound.

Brilliant effects.

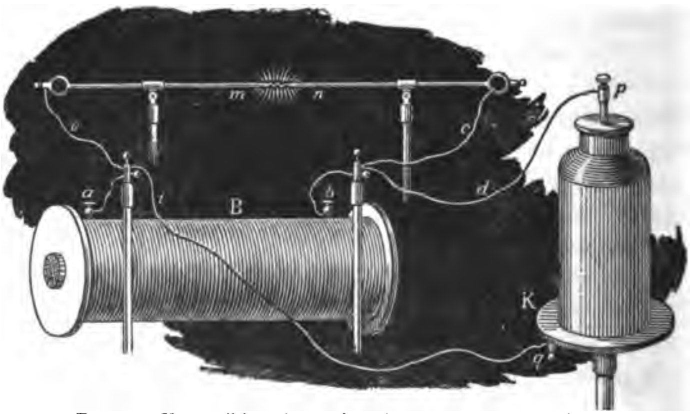


Fig. 210.—Very brilliant detonating discharges obtained by introducing Leyden Jar in circuit of Ruhmkorff secondary terminals.

The expanding and contracting lines of magnetic force produced around the axis of a conductor, when the currents passing through it are rapidly undergoing changes in strength, may be caused to cut or pass through parts of its own circuit, and thus produce self-induction therein. When the circuit takes the shape of a single straight conductor, the return of which is also formed by another single straight conductor parallel to the first, the effects of self-induction are almost absent; but, when the conductor is closely coiled on itself in the shape of a coil or helix, then the effects of self-induction may become well marked, especially if the coils are wound around a core of soft iron wires, as in the case of an ordinary electro-magnet.

Circumstances under which self-induction is almost absent.

If the terminals of a single voltaic cell be connected to an electro-magnet, practically no spark will be seen on making or closing the circuit; but, on breaking the circuit, a bright spark will occur, and, if the number of turns of wire on the electro-magnet be great, and a fairly powerful current be flowing through its magnetizing coils, the E.M.F. and current produced by self-induction may be sufficiently great to give a severe shock to a person holding the terminals of the electro-magnet in his hands.

Powerful current produced by self-induction on breaking circuit of electro-magnet.

The electric currents thus produced by self-induction are called extra currents. The current produced on making the circuit flows in the opposite direction to the current flowing through the coils, and thus delays the establishment of the full current strength in the circuit. That produced on breaking the circuit flows in the same direction as the current through the coil, and thus tends to prolong the passage of the current, or to oppose its cessation. This latter extra current appears as a bright spark of far greater E.M.F. than that of the current which produces it. We will see that extra currents produced by self-induction tend to greatly retard the speed of signalling in electro-magnetic telegraphy, from the fact that they tend to oppose either a rapid increase or a rapid decrease in the strength of the current flowing over the telegraph lines.

Extra currents.

Extra direct current on breaking circuit the most powerful.

The increase in the value of the E.M.F. of the extra current produced on breaking the circuit of a coil of many turns, wound around a soft iron core, is taken advantage of in apparatus where gas-jets are ignited by means of electric sparks in an apparatus called the spark coil. The spark coil consists

Spark coil.

of a coil of insulated wire wrapped around a core consisting of a bundle of soft iron wires, that is introduced in the hollow core represented in Fig. 211.

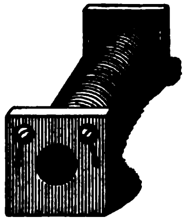


Fig. 211.—Spark Coil employed in igniting Gas-jets.

Henry's coils for self-induction.

Extended researches both in mutual and self-induction were carried on in the United States at a comparatively early date by Prof. Joseph Henry, of Princeton, N. J. During these investigations, Henry found that when a current from ten voltaic

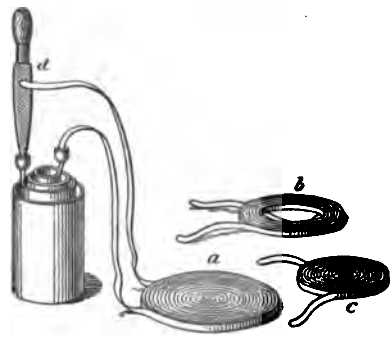


Fig. 212.—Henry's Coils for demonstrating phenomena of Self-induction. Note that additional spirals or coils, *b* and *c*, were provided to show the effect the length of the coils had on the E.M.F. of the sparks produced.

Discharges too powerful to be taken with safety.

cells was passed through a spiral of copper wire, some five miles in length, the discharges produced were too powerful to be taken with safety; that when the current from a battery consisting of six very small voltaic cells was sent through this spiral, the

discharge was sufficient to give a shock to twenty-six people, placed in single circuit by joining hands. The simple but exceedingly efficient method employed by Henry for obtaining these effects, is shown in connection with Fig. 212, where an ordinary file, *d*, has one end inserted in one of the poles of a single voltaic cell, and one terminal of a long coil, *a*, composed of a flat copper ribbon, inserted in the other pole of the cell. By rapidly moving the other end of the coil over the file a series of successives makes and breaks were produced, the discharges following the successive breakings manifesting themselves by bright sparks.

Henry's use of a file for making and breaking the circuit.

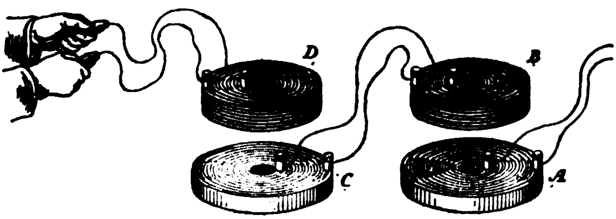


FIG. 213.—Henry's Coils for producing phenomena of Mutual Induction.

By employing a series of coils formed of copper ribbon alternating with helices of insulated wire of fine copper, Henry succeeded in demonstrating that a secondary current induced by a primary, could act to produce other induced currents of the second, third, fourth, and so on, as high as the ninth order; thus, the flat spiral A, Fig. 213, receiving a rapidly broken current from a battery produced induction currents in B. If, now, B is connected, as shown, with the second flat spiral C, it may be made to act inductively, and thus produce tertiary currents in the coil D.

Henry's coils for mutual induction.

The discharge from a Leyden jar, if sent through

a copper spiral, will induce currents in a second copper spiral placed near it. Matteucci demonstrated this fact by connecting the coatings of a Leyden jar, I, Fig. 214, with the terminals of a copper wire, A, spirally wound on the surface of a disk of gutta-percha. He showed that, under these cir-

Matteucci's experiments on induction from Leyden-jar discharges.

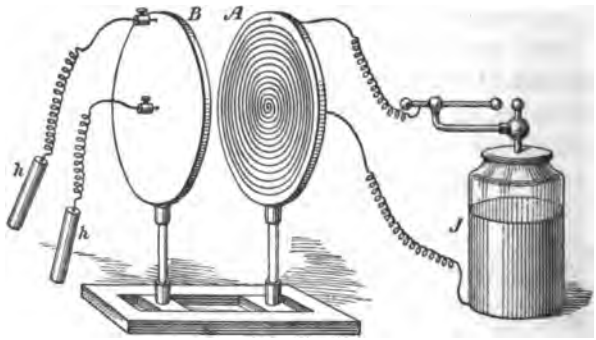


FIG. 214.—Matteucci's production of Induced Currents from Leyden-jar discharge.

cumstances, the discharge of the Leyden jar would produce currents by induction. On the discharge of the Leyden jar through A, a shock will be given to a person grasping the handles *h, h,* connected with the second spiral B. The intensity of this shock varied with the distance between the spirals A and B.

INDEX

A

B

C

D

G

H

I

J

K

L

Q

R

S

U

END OF VOLUME ONE